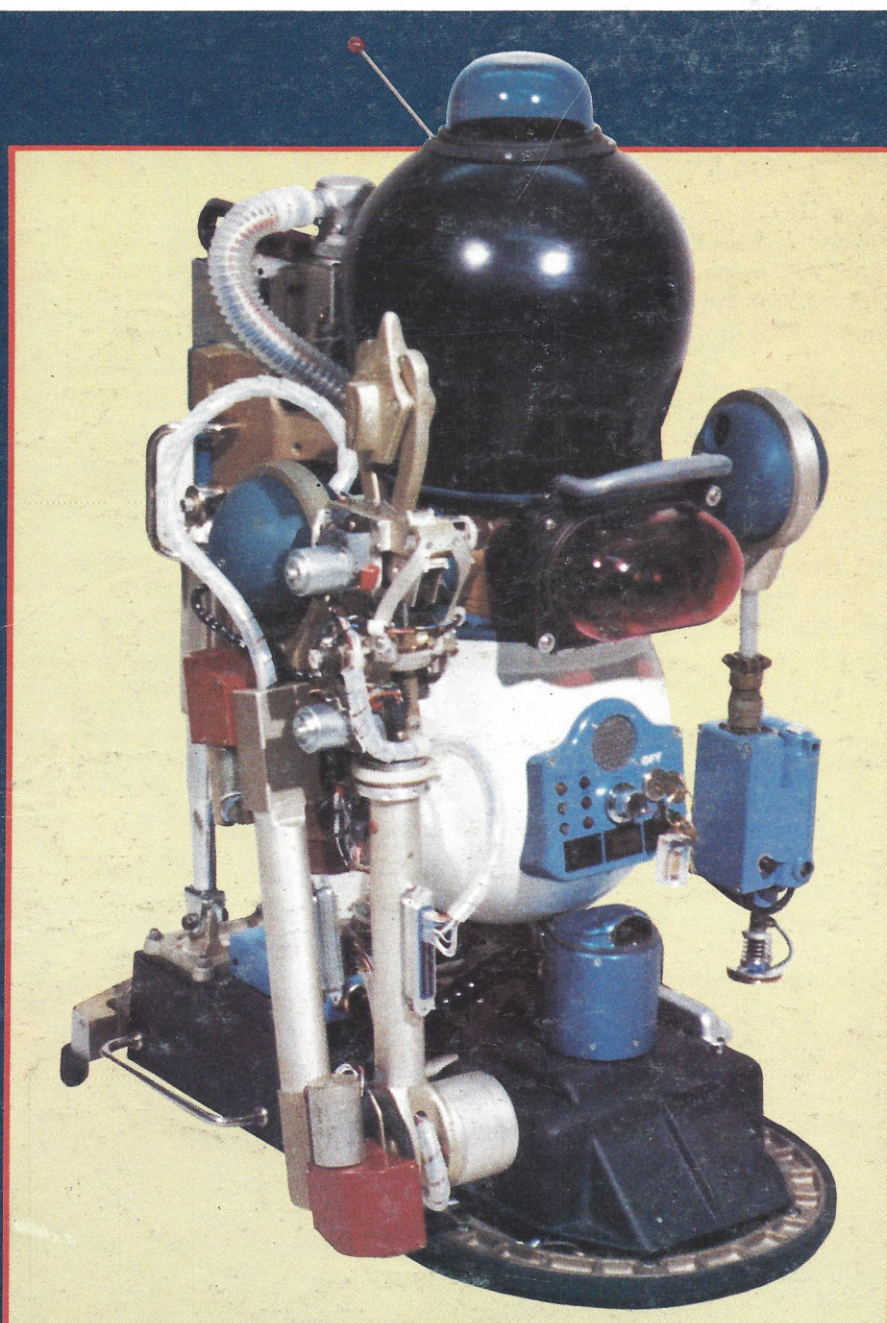


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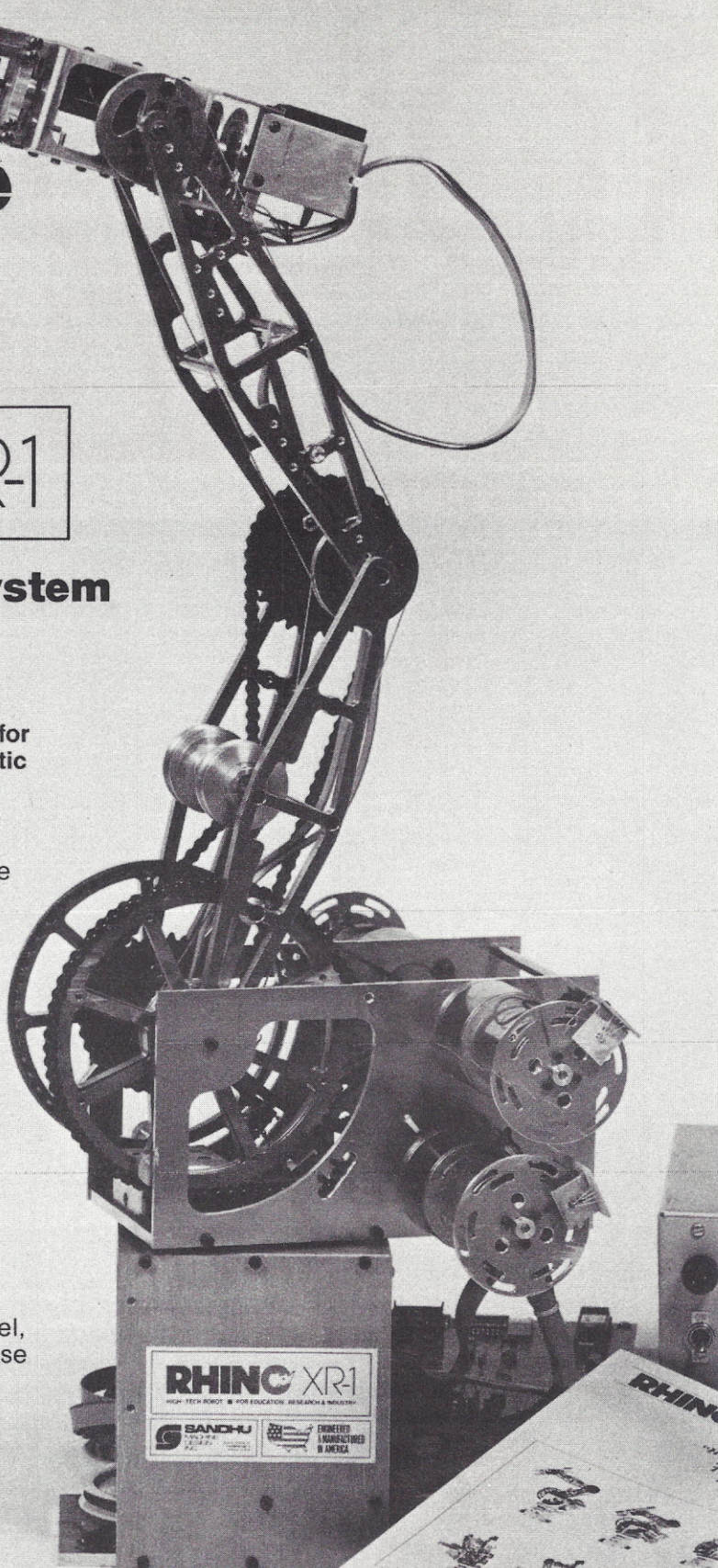
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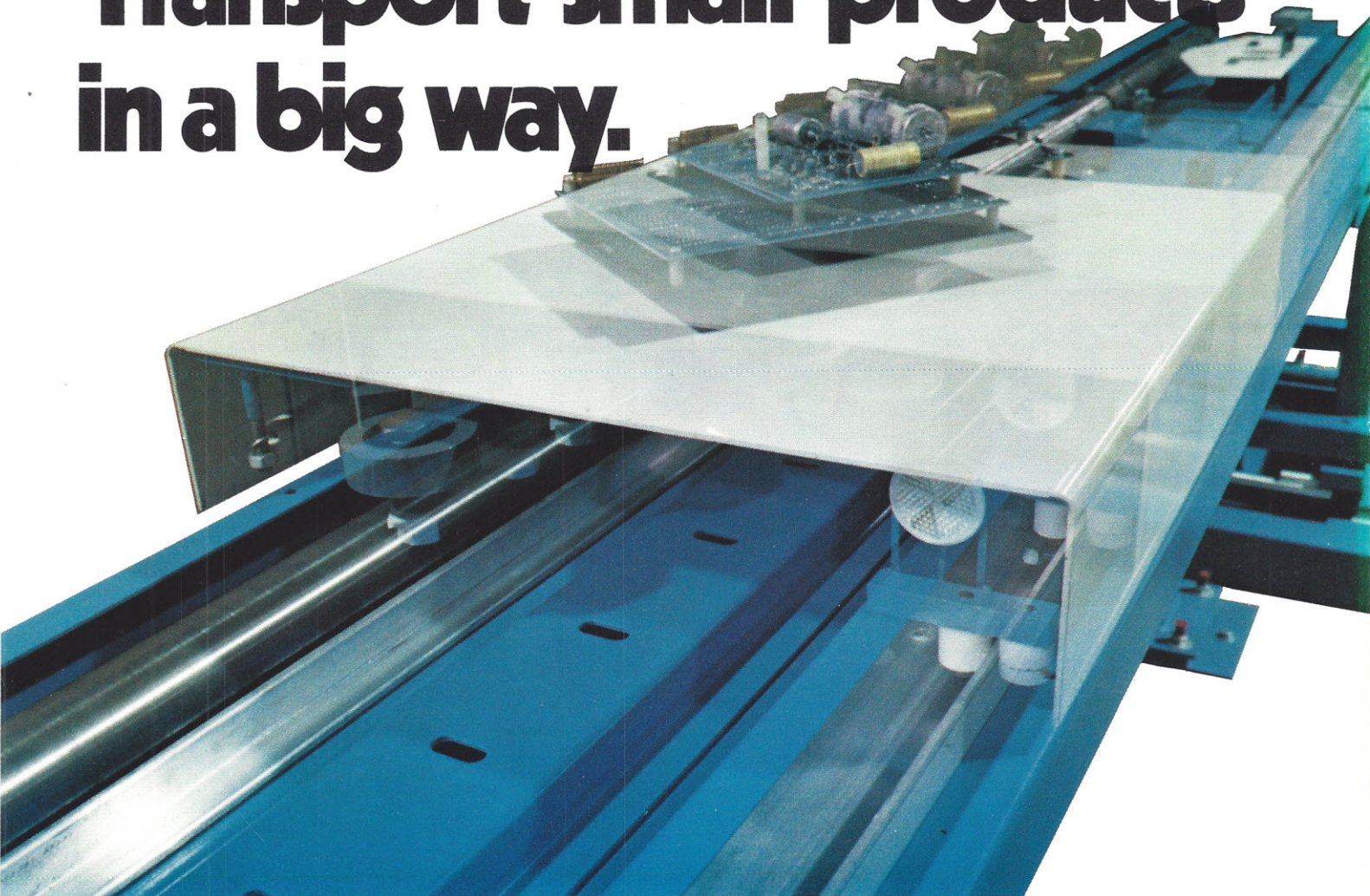


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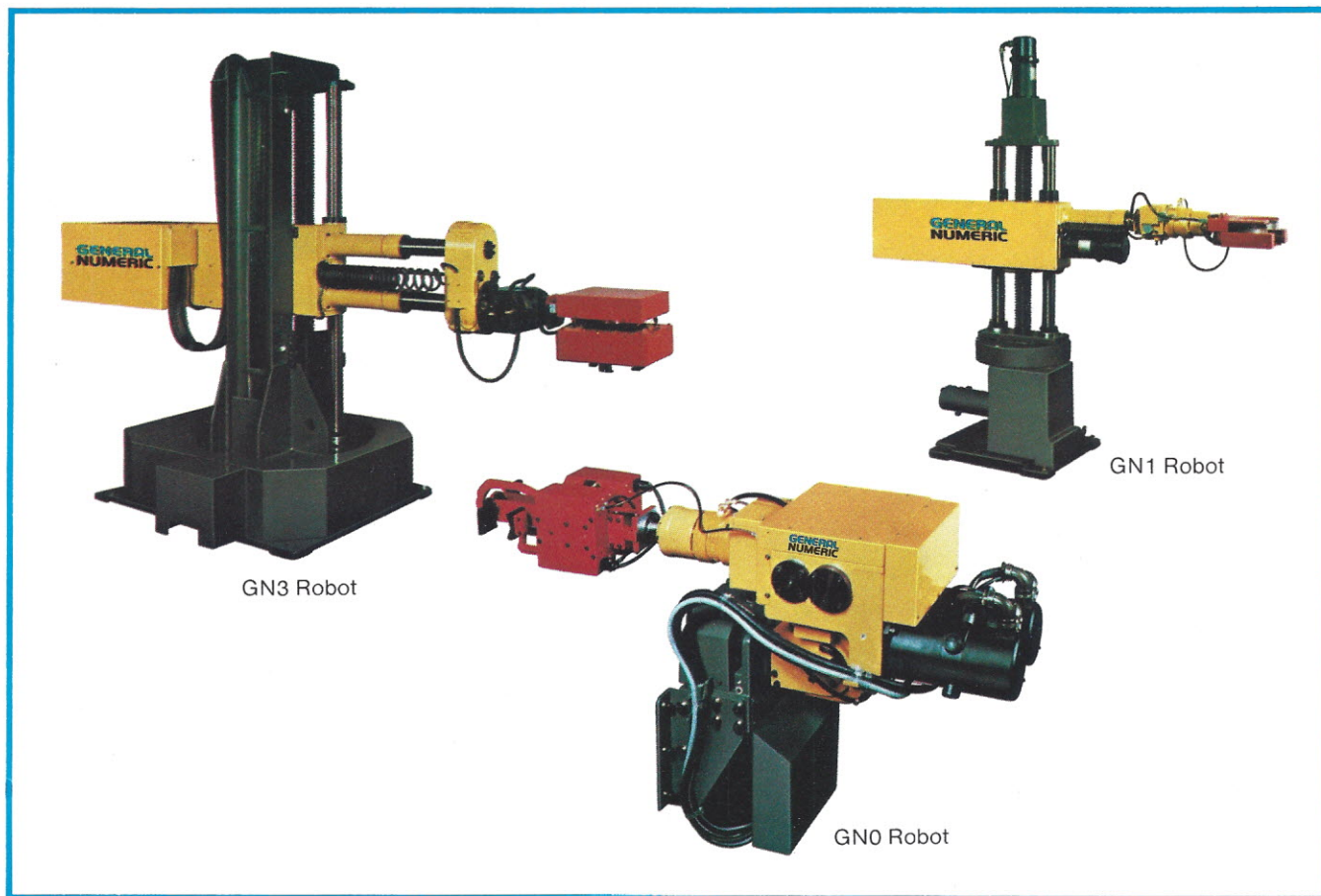
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Editor

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Associate Editor

Raymond G. A. Cote

Editorial Assistant

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Scott Nowell

Typography

Reprographics

Technical Illustrations

Techart Associates

Consulting Designer

Robert Tinney

Publisher

Glen W. Swanson

Advertising & Marketing

Laura A. Hanson

Business Systems,**Circulation & Dealer Sales**

James Bingham

Printing

Wellesley Press

Founder

Philip C. Flora

Advertising Sales Offices**General Advertising Sales**

Laura A. Hanson

Robotics Age Inc.

174 Concord Street

Peterborough, NH 03458

603-924-7136

Industrial Advertising Sales

Philip C. Flora

Technical Database Corporation

P.O. Box 725

Canada, CA 91011

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

JAN/FEB 1982

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About the Cover: The prize winning robot, Avatar, photographed by its designer Charles Balmer.

ROBOTICS AGE — USPS 523850 (ISSN 0197-1905) is published six times a year in January, March, May, July, September and November by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, N.H. 03458, phone (603) 924-7136. Address subscriptions, change of address, USPS Form 3579, and fulfillment questions to *Robotics Age* SUBSCRIPTIONS, P.O. Box 358, Peterborough, N.H. 03458. Second class postage paid at Peterborough N.H. and at additional mailing offices.

Subscriptions are \$15 for one year (6 issues), \$28 for two years (12 issues), \$39 for three years (18 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are \$17 for one year, \$32 for two years, \$45 for three years. For other countries, subscriptions are \$19 for one year surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is \$3 in the U.S., \$3.50 in Canada and Mexico, \$4 in Europe, and \$4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

Address all editorial correspondence to the Editor, at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, N.H. 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, the *Robotics Age* Authors' Guide is available upon request if accompanied by a self-addressed 8½ inch by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

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Robotics: New Directions and New Excitement

by Carl Helmers

There are new directions behind the new *Robotics Age* you see opened in front of you. The new directions are those of serving the needs of the modern intelligent systems experimenter in an era of improved low-cost mechanical, electronic, and artificial intelligence technology. Our aim is to provide an interactive forum for ideas about the design and implementation of "intelligent machines," machines that apply computer control strategies to automated interaction with their environments. This is a wide range that includes many levels of control and interaction — all tied to the use of modern silicon computer and electronics technology for implementing details of design.

Just what is a "machine?" How can it possibly be considered "intelligent?" We certainly don't mean a machine that takes intelligence to design. All machines are artifacts of human activity constructed for some real or imagined use as a tool. Not all machines are intelligent — does a hammer in use have any intelligence to it, apart from the carpenter's control of his arm and his hand holding it?

In contrast to the hammer, many modern artifacts have an interactive intelligence. An arcade game is a machine of enjoyment. A robotic arm is a machine of production. Both are intelligent machines which employ an intelligent control algorithm executed in a context of interaction with its environment. A computer by itself is devoid of the purposefulness of the intelligent machine in a human context. It must be programmed and filled with peripherals. A hydraulic ram by itself is similarly devoid of purpose. Its marching orders must be received from a trained operator. Add the appropriate interface between an intelligently programmed computer and the powerful ram, and the result is a form of intelligent machine used in some application context.

The experimental technology concepts that are our editorial focus range from the dedicated fixed program

microcomputer controllers of today's household environment to the design experimentation needed to produce tomorrow's household robots. They include robotic arms from the industrial production line and the arms which pluck satellites from orbit in modern spacecraft. Among them are the various kinds of computer augmented prosthetics for people who have handicaps. Included are programs and software that simulate non-existent machines and the computer software necessary to control real machines. They include artificial intelligence software for gaining information from fuzzy sensor images — and clever hardware and software combinations to implement new sensor strategies. Above all, this technology is an uncharted realm of human endeavor, a realm that will be promoted and accentuated by the new *Robotics Age* magazine.

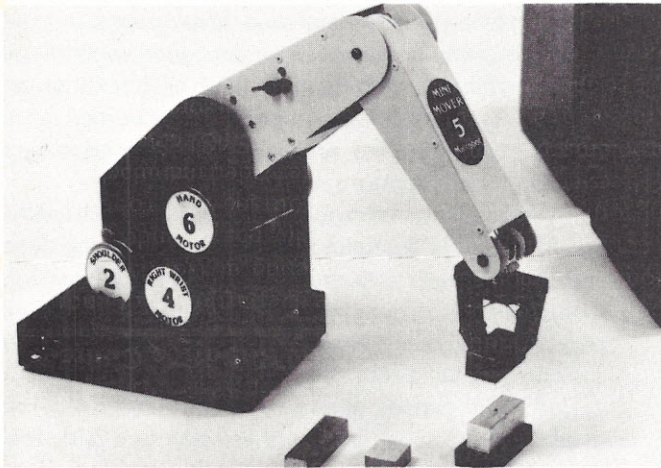
The New *Robotics Age* Magazine is a Forum

A magazine like *Robotics Age* is an interactive and participatory forum for all its readers' interests. What kinds of ideas will readers see in this forum? Our readers are our writers. Those actively working in this field of endeavor communicate with their fellows through the written word as prepared and delivered on a regular basis. Those actively learning about some aspect of the field will read our articles as a prime source of information. Those actively experimenting with intelligent machine concepts see a valuable stream of ideas about design and implementation.

As a forum, the new *Robotics Age* is a public place. Ideas are presented for use by all who will read and take them under consideration. Our forum's reason for existence is intelligent machines. This is a broad subject area with many facets.

There are a number of ways to view the problem of intelligent machine design. We could, for example, consider the measure of system complexity. This starts at a low level

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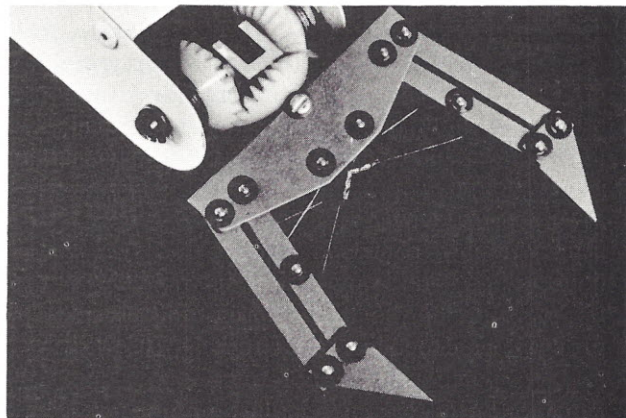
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Editorial

with the simple home or factory control subsystem. As we add function and complexity, we find such examples as cooking appliance controllers, burglar alarms, and the like. In the factory, we see simple numerical control of conventional tools as well as unconventional but simple tools like robotic arms with pattern memories. At some point, we add sensing of the real world and interaction, resulting in yet another level of complexity.

In the world of intelligent machine development tools, we see the small personal computer. We also see various fifth generation specialized artificial intelligence software development computers beginning to spring forth as commercial projects. In the world of practical robotics applications, we are seeing the robot arm coupled with tactile or visual sensory feedback. In the world of the home or office environment we see the personal computer running advanced programs derived from artificial intelligence research. In the world of industry, we see the completely automatic factory concept. Ultimately, true believers in science fiction expect to see the personal robot servant. These are all representative of variations in the relative degree of complexity.

Another way to consider the problem is by a measure of the degree of "reality." This is a way of looking at the software component of the intelligent system. At one extreme we see the totally simulated environment — with no ties to the real world other than the computer upon which the simulation program is run. At the other extreme we see the robotic intelligent system embodied in a mechanical or electronic environment of the "real" world. In the simulated world, difficult problems can temporarily be made to go away by defining them out of existence. In the real world, such problems are not so simple to resolve. This simulation versus reality axis can be an illuminating way to look at the robotic system.

We can of course take a microscope to any problem. Much of the exciting content of this forum is devoted to views through a conceptual microscope, looking at bits and pieces which are understood to be used in a larger context of intelligent machines. Thus, we take apart intelligent machines and examine their design principles. Thus, we examine details such as sensor input techniques, electro-mechanical subsystems techniques, mechanical design and fabrication techniques, knowledge acquisition and decision software techniques, algorithms for accomplishing various tasks. There is the whole subject of robot-building tools and techniques ranging from the machine shop to the software development computer. These microcosms of the intelligent machine perspective are the basis from which many forthcoming articles will be drawn.

As an editorial forum for the experimental designers and creative innovators of the world, this new *Robotics Age* addresses itself to the mechanics, electronics, simulation, software, and artificial intelligence of intelligent machines. In a

manner similar to the early personal computer era, significant "intelligent systems" laboratories can be put together by individuals and small companies for experimentation and product development. With adequate funding, many large companies are devoting research and development resources to the same goals. However it is funded, such experimentation is a part of that great human tradition of innovation and invention. A major portion of our editorial focus is on the readily available tools, supplies, and techniques needed to equip the development laboratory, regardless of its scale.

In the past I have often made a comment which I will repeat again: we are in an era comparable to the setting described in Robert Heinlein's science fiction book, *Door Into Summer*. Computers and memories are available off the shelf. To paraphrase his commentaries, when it is time to build robotic systems, we build robotic systems. And that time is now.

Parts and pieces abound, in standard forms readily available at low cost. Putting these standard parts together into a prototype, then a manufacturable, intelligent system is one of the great technological challenges of our day. The new *Robotics Age* is your source of information — both advertising and editorial — for the essential tools, resources, and techniques of the era of intelligent machines. That we can now provide such a forum for the information needs and enlightenment of our readers is a result of the growth in this field. Robotics in particular and intelligent machines in general are a major thrust of technological growth in the 1980's.

As a source of information, the new *Robotics Age* provides a unique combination that is unavailable elsewhere. All of our readers gain an enrichment and an enhanced perception of the problems of intelligent interactive systems. This journal is the focal point of a multi-disciplinary view of engineering, physics, mathematics, economics, and philosophy. It also defines an active and growing marketplace for products related to smart machines, their design and application.

Who among our readers will be turned on by the excitement of robotics and put together a company the likes of Apple Computer or Personal Software? We feel that similar opportunities will abound in the field of intelligent machine design and use. The new *Robotics Age* chronicles for our readers the same kind of excitement for the 1980's that minicomputers, then microcomputers, provided for the 1970's. It provides a source and forum for ideas. From ideas, new products will grow.

A Timely and Entertaining Compendium of Information

The new *Robotics Age* has a charter of presenting information about intelligent machines in general, and robots in particular. This charter is carried out through the efforts of the writers, people who are actively involved in investigations of the art. The era of intelligent machines is an era of individual

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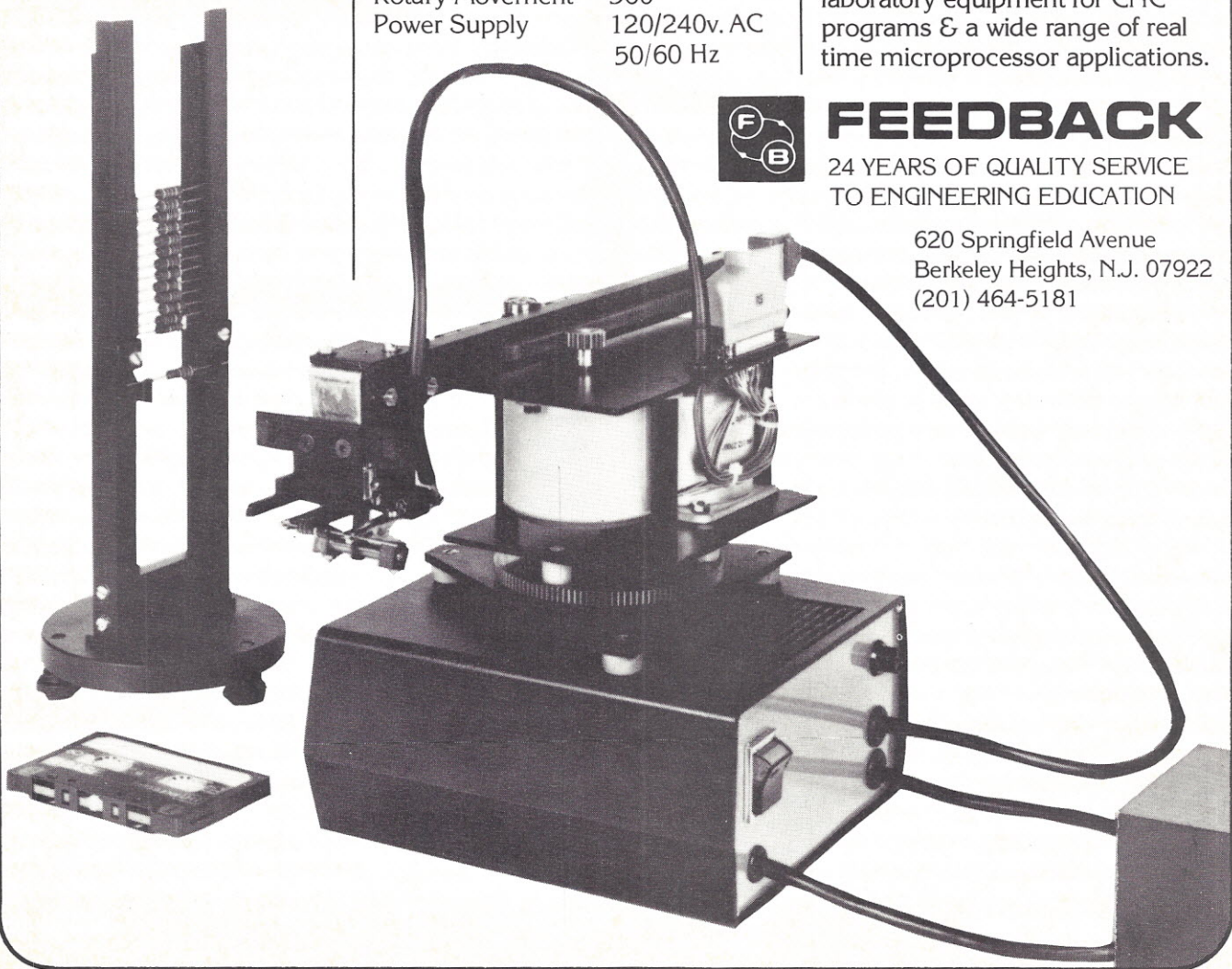
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Editorial

experimentation enabled by the recent advances in microprocessor and personal computer technology. *Robotics Age* is the journal of record for a new generation of technology that will unfold throughout the 1980's. The topics cover a broad range, a range we'll suggest by mentioning a few ideas we should see developed in future articles.

We Seek Ideas From Existing Systems

As experimenters we're most concerned with the technology of intelligent machines. What do we mean by intelligent machines? Begging the question of what we mean by intelligent and machine, to first order — an intelligent machine is any artificially constructed system that contains a computer with operational software. It may involve a computer in an isolated solo box, or a computer that talks to an automated home or factory. It may mean a computer built into an intelligent toy, or a microprocessor in the node of a local network communications system.

These are the machines we experiment with at work as computer engineers, electronic engineers, scientists, and students of modern technologies. We experiment with these machines and design concepts in order to try new approaches, solve new problems, invent new problems, and otherwise sharpen our intellects and skills.

The art of intelligent machine design and implementation can often be illuminated by that noble art practice of reverse engineering an existing system. Many of us began this practice as children — that alarm clock we took apart in kindergarten, that radio or television we took apart to find out what tubes were involved. As adults, we can learn about design choices and options by analyzing the microprocessor products we see all over the technological landscape. Sometimes the published analysis of the intelligent system is written by the designers of the system, as in the case of the first Type-N-Talk article published in *Robotics Age* last year.

In other cases, the published analysis is made by another individual. In the absence of the original designer, an intelligent toy or appliance can be analyzed and used as an example to teach principles of design for manufacturability and utility. A second article we'll be publishing concerns user reactions to the Type-N-Talk product, and an analysis of its function from other than a designer's point of view.

An analysis may even reveal ways of incorporating the system into other experimental systems. Thus, an analysis of the principles of the BSR X-10 home control system soon suggests how it can be controlled by the personal computer system, leading to the intelligent, robotized house concept.

In the ultimate case of reverse engineering, analysis of biological systems lends ideas to the design of new mechanical and information systems of the robotics age. If Nature's evolution leads to design approaches that work, our imperfect

copies in computers and robotics may also work. In an ironic twist, the brain scientists suggest ways of organizing the computer "mind" while the computer scientists suggest ways of comparing a molecular biologist's DNA to large arrays of encoded information bits.

This kind of analysis of existing "smart machines" is one of the most important priorities on our editorial list. Whether the model is natural, or mass produced and commercial, the information helps in creating a new solution to a problem. Analysis suggests new products. Analysis creates better understanding.

Robotics is an Engineering Discipline

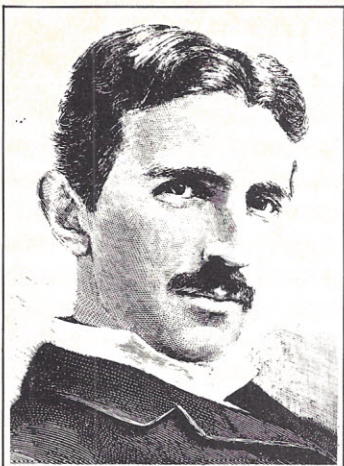
The activity involved is engineering. Engineering is the art of applied design science. A scientist discovers the principles of Nature, and the engineer applies these principles to specific and limited contexts of human use. Viewed in this light, the idea of "robotics" is that of intelligent machine engineering, growing out of a fortunate combination of prior engineering and applied science fields: computer science and mathematics, electronics, mechanical and materials sciences, and, of course, physics.

The first scientist might have been the cave man who discovered that hot obsidian from a fire might flake into a sharp edge if dumped into water. The first engineer was that cave man's brother in spirit who figured out how to make a knife out of the sharp obsidian fragment in order to cut the roast that was cooking on the fire. The reverse engineering in this case is supplied by an archeologist with knowledge of applied physics and materials science. Like a true sleuth he determines the origin of the blade from analysis of sketchy details.

The art of building intelligent machines is simply the latest example of the human propensity for imaginative innovation coupled with practical application. A magazine such as *Robotics Age* provides a much more complete record of the excitement in our era than is ever available to the archeologist.

The kinds of innovations that define a given field depend heavily upon its component subjects. In the area of robotic experimentation, we find a set of topics, a set of related tools, and a set of inspirational models from science fiction and fantasy. Key elements of the practical experimentation are the tools and standard parts that make up the modern environment of engineering. Design is almost always a non-standard combination of standard parts and procedures, with an occasional custom interface thrown in.

Without standard hardware and software parts, too much time would be spent re-inventing numerous essential wheels. That cave man only had some volcanic glass lying about. We twenty-first century innovators still use derivatives of volcanic glass, but highly purified into the tiny silicon lumps called microprocessors and related integrated circuits. One of our



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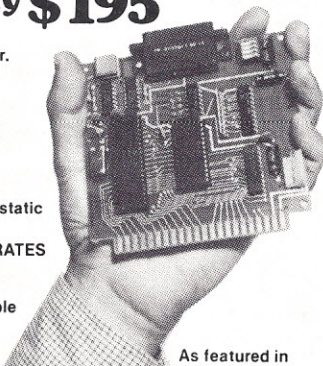
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July and August 1981.



Editorial

goals in publishing this journal is to reduce redundant wheelmaking by exchanges of information in these pages.

The suite of components of machine intelligence engineering includes many elements. We need to address each detail, yet preserve the overall plan. The modern roboteer must be intimately familiar with electronic design, mechanical design, software design, epistemology, and concepts of system design that embrace all these disciplines. The individual who would be a productive innovator in robotics must aspire to the diversity of a renaissance man.

In presenting this package of information for the true robotics and artificial intelligence experimenter, we must cover a broad range of fundamental information. This information is in the form of episodic chunks known as magazine articles. These range from the abstract tutorial to practical details, from the pure software concepts of languages to the pure hardware concepts of power servomechanisms, from the images of science fiction to the practical realities of mobile, battery powered robotic vehicles. This is the charter of the new *Robotics Age* magazine.

Getting Practical — The Execution of a Design

Performing the complete function of an information service, we cannot avoid celebrating the practical techniques and methods of the experimenter. It is one thing to talk rhapsodically about the wonders of the new age. You can turn to any number of newsstand magazines for repeats of this formula. In this journal, we take the rhapsody one level further by examining the nuts, bolts, and error correcting codes of the technology.

The new *Robotics Age* is a vehicle for information about "how to," as well as "who," "what," and "where." It is not an easy feat to accomplish, since it requires the participation of people who are part of the intelligent machines culture. We do not enter this enterprise as journalists, but as actual experimenters who are a part of the same milieu as our readers. This is what makes a vital, active, special-purpose journal like the new *Robotics Age* work. The childhood bromide of "it takes one to know one" has an adult aura of truth to it in this field as in many others.

A major part of our tutorial goal is to present practical techniques for the complete robotics experimenter. For the reader who has a background as an electronic systems engineer, computer scientist or technology-oriented generalist, the obvious information needs of greatest importance are related to the design and implementation of mechanisms. We will thus find some of the important design and fabrication concepts appropriate to three-dimensional forms of robots in the real world. We can expect our more mechanically oriented reader/writers to provide information for this forum, covering such topics as shop technique in general and specific technologies such as use and abuse of

Editorial

machine tools, custom metal castings, mechanical design, strength of materials, and welding.

For the reader whose background is grounded in the mechanical and fabrication arts, the obvious information needs are those related to design and implementation of system concepts in electronics and computers. Thus there is a heavy emphasis in the new *Robotics Age* upon computer engineering, ranging from artificial intelligence to language design to processor design to the design of practical electronic interfaces. We can expect contributions from philosophers of software, practical software developers, and experimenters with personal computers to fill this area of the editorial bill.

Getting Theoretical — Or Systems and Software Oriented

Computer systems and software are an integral part of the whole robotics and intelligent machine concept. One cannot conceive of any application of robotics that doesn't somehow use modern small computer technologies. A major part of our editorial emphasis is thus on somewhat abstract — yet eminently practical — concepts of systems design and software.

The questions range from the issues of simulation, to the issues of implementation. A good design starts from an idea, is elaborated in practice, and is still as simple in principle when complete as when it was begun. The modern engineer applies the principles of modular stepwise refinement of design to all phases of the project that is involved. In computer and systems software, this is the most important design tool of structured programming. Stepwise refinement, modularity and elimination of interaction side effects apply just as well to real world models and real world systems such as those mechanical systems identified with robotics. The modern robotics experimenter will use this approach, as encouraged by the articles in this forum. How are systems designed, how do they react? Where are reasonable places to draw the lines between parts of a system?

Given the fact that we humans must interact with the systems we design, what are the human factors? The fundamental principles of friendly interaction are one of the major components of good design. This is true in the home, the factory, the school, or any other context in which people interact with computer systems. The robot with a lisp to its voice is hard to understand. The artificial intelligence augmented database with obscure search rules is hard to use. The command keyboard with an inappropriately placed "reset" key is confusing — if not dangerous — to use. We will explore design choices, contemporary examples, and even occasional design disasters as part of this tutorial message about human interaction design.

All of our new machine intelligence technology is based on computers, and on a particular branch of the computer science

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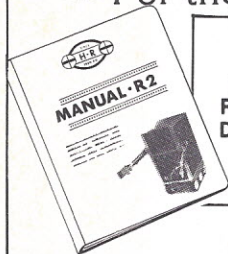
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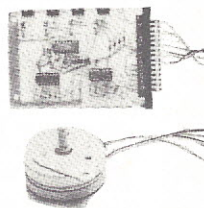
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Editorial

endeavor often called "artificial intelligence." One common but far from precise definition of an artificial intelligence capability in a computer system is incomprehensibility. A system can be said to exhibit artificial intelligence if it has behaviors too subtle or complex for trivial understanding. By this rule, human beings could be called artificially intelligent.

A more useful criterion would be to call artificial intelligence research the study of difficult problems not formerly thought amenable to computer-oriented solutions. Under this criterion we can easily embrace concepts from natural language understanding to "blocks world" simulations of three-dimensional manipulator actions. Under this definition, we can include "expert systems" and computer vision studies. Grand master chess is an obvious and nearly accomplished triumph of artificial intelligence research. Design and implementation of different computer architectures for artificial intelligence research falls in this category of systems and software issues.

When talking about systems and software development, we soon come to the questions of development systems. These questions of development systems and methods of interaction are of crucial importance to those who engineer intelligent systems. There is ample incentive to cover topics like high-level languages, specification and selection of hardware and software development systems, and peripherals of conventional and exotic varieties. We will see many articles on this theme over the course of coming years, for no robotic system — from the factory to the automated house — can be developed without addressing the issues of software design and hardware interactions with software.

The development system has to develop something, or why use it in the first place? When extending the concept of an intelligent machine beyond the boundaries of the mute and self-contained computer system, we are talking about the general area of artificial perception and its implementation. In order for an artificial intelligence to interact with the world of people and things, it must have some form of artificial perception. The principles of sensor design and application in feedback loops are key points of discussion in the world of robotics and intelligent machines. The sensor perceptions of our designs use this information to fill in the details of internal "world models," which serve as a guide to action and interaction.

We'll be talking about sensors for chemical phenomenon, analogous to smell. There are sensors for the resistance and tactile "feel" of mechanisms, analogous to the kinesthetic sense of organisms like humans. Of course, vision and hearing in their electronic sensor analogs are important parts of the real world robot with mechanical effectors. These two problems are perhaps the toughest to lick. When we look into communications among intelligent systems via radio and cable links, we are talking about a true implementation of

Editorial

telepathy in a robotic sense. All of these perceptions are important for the intelligent machine integrated into a real world environment beyond that of the simple computer terminal.

Answering That Crucial Question: "Why?"

Above all, this journal is a vehicle for answering the ultimate question about intelligent machine technology: "Why?" Why build a robot? Why make an artificially intelligent muse? Why extend the boundaries of engineering theory and practice? These questions are not meaningless. We don't engage in this art and science simply for the neatness of it. There is an element of satisfaction that comes from knowledge and design abilities in all of our readers — but that is a side effect of one of our real goals. As engineering-oriented technologists, we ultimately justify our efforts on the basis of their practical and beneficial effects for the human condition. Here is the most exciting area of our endeavors: investigating new and productive possibilities for the application of our technologies.

We never know about practicality until we try our ideas in real systems. This is the ultimate goal of all research and development. Find out what the problems are. Explore an idea and see if it will work in practice.

Negative Feedback

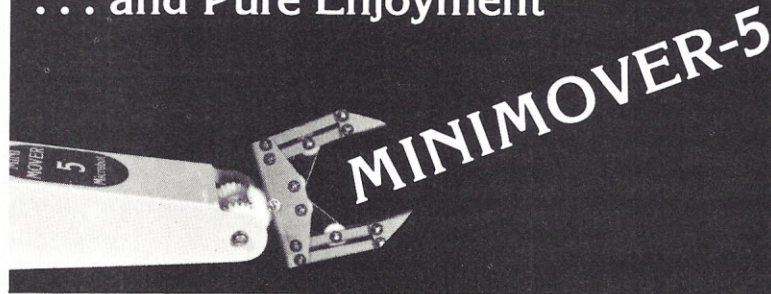
A tightly controlled system uses small amounts of negative feedback to achieve and maintain its set point. Sometimes the Feedback is internal to the system, sometimes it involves cooperation in a larger context. While perusing the November/December issue, we found an example of such an error signal — and generate this negative feedback input. The captions of the two photographs on page 34 were switched. As printed, the photo at the left is the Yaskawa Motoman-L10 arc welding robot. The photo on the right was, of course, a Unimation Puma of Kawasaki Manufacture.

This area of applications is the study of human structured environments and the way our machines fit them. When we talk about mobile self-contained servant machines, we talk about applications to specific limited environments of human factories, offices, hospitals, and homes on this planet. These applications already exist in the business world, in such forms as robot mail carts and robot food service carts in certain office- and hospital-oriented systems. This servant machine concept will eventually evolve into the household robot which so tantalizes the imagination of the more dedicated experimental roboteers. There is a whole industry waiting for the automation of many domestic and household functions by means of the general-purpose robot. It may take ten or twenty years to unfold, but it is coming.

In the current era with current technology, a very vital and important application is the prosthetic manipulator. Here we talk about the replacement of damaged human limbs with robotic manipulators. As seen in prior articles in this publication, today's systems are an important step toward amelioration of human suffering.

On this same note, robotics holds out the benefit of helping to reduce the need for such prosthetic fixes. If we eliminate unnecessary hazards through teleoperators and autonomous

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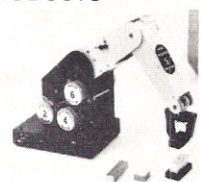
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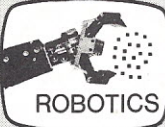
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Editorial

robotic machines, then fewer damaging accidents will occur. Some of the earliest work with teleoperators, for example, is now a standard part of the technology of the nuclear industry. The hazardous environment of high radiation levels is avoided through the use of such remote manipulators. And everyone knows how we investigate the harsh environments deep under the sea — or deep into space — with semi-autonomous and autonomous explorers. In many cases, these environments have cost effective engineering solutions where the humans remain in a safe, protected environment, while communicating with exploration vehicles.

The same principle applies to many mundane and "ordinary" hazardous environments of modern civilization. When we return to the earth with the same harsh environment concepts, we talk of saving lives in mining through the use of intelligent machines — or saving human lives by use of machinery in boring or hazardous jobs in factories. Similarly, when the science fiction dream of the robot chauffeured automobile is achieved, there may be fewer deaths on the highway. (For those who have doubts, we're close to that goal in the sphere of aerospace, where autopilot, automated radar warning, and air traffic control advances are happening at a fast pace.)

There are activities of intelligent machines in the simple interaction and sensor models of the desk top computer, applications that are legitimate and demonstrative of the concept of the abstract concept of a robot. When we talk about the fields of real world simulations, text processing automats with language understanding, and database concepts, we are talking about the abstract "intelligent machine." The internal world model point of view that we use so effectively in designing and building the interactive robot applies to these logical constructions as well. The interactions are involved in a "data world" accessed through keyboards and displays. The results might be symbolic integrations of mathematical functions, graphical representations of databases, or even simple understanding of English language questions posed by voice. This is the computational aspect of all robotic systems, taken in isolation in intelligent machines that have little direct sensor and effector ties to the real world.

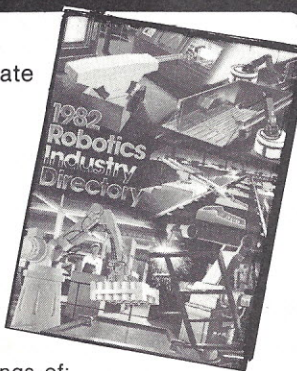
Summing Up

The sphere of technological ideas we'll be covering in the pages of the new *Robotics Age* magazine is wide. Whatever the detail topic, the central thread of all our information is the design and application of modern intelligent machine concepts. This represents the ultimate human activity on this planet to date, an outgrowth of the past fifty years of exploration in electronics, aerospace, machine design, and automation. This is our editorial territory. Each issue of this journal of intelligent machines is a new world for our readers to explore.

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What is This Robotics Age?

This Robotics Age is the beginning of a renewed and soon to be enlarged stream of information about the most exciting development in human technology of the 1980's and beyond: intelligent machines and their uses. This Robotics Age is the first issue of a new editorial product with a new editor. In coming months we will see an expansion of interactive dialog in these pages as Robotics Age grows in readership and frequency of publication.

Let me introduce myself. My name is Carl Helmers. I am a long time believer in the inspirational value of science fiction. I am a thinker and experimenter by nature. I occasionally write about the technological ferment that is producing exciting advancements we see in electronics, computers, robotics, genetics, and space travel.

I read my first science fiction book at the age of eleven. I spent my youth as "... the kid in your high school who always went around with a slide rule dangling from his belt — the one who called it a 'slip stick.'*" I earned an undergraduate degree in physics, paid for by taking summer programming jobs, and went to work on a project to produce software tools for development of Space Shuttle flight programs in the early 1970's. But I had not found my calling. I spent much of my time tinkering with electronics and computer-related applications, writing about the experiments, and publishing the results myself.

In 1975, I found my "true" calling... putting together that mysterious combination of readers and writers which defines the editorial end of a special-purpose magazine devoted to technological experimentation with contemporary engineering concepts. With much help from hundreds of writers who were also readers, I created and set the directions for an idea forum called BYTE, which became the bible of the personal computer field. In that previous context I often wrote about and encouraged work in that classic of science fiction: robotics and artificial intelligence. My involvement with BYTE ended in 1980.

Last fall, Robotics Age's founder and first publisher, Phil Flora, came to me with a problem. After two years of presiding over the editorial birth of a magazine, Robotics Age's founding editor, Alan Thompson, had decided to return to a life of teaching and research in the field of robotics. Would I care to turn my efforts to a new editorial project? Having known Phil for several years through my artist friend Robert Tinney, I invited him to stop by and talk on his next trip east. Talk we did. The result is a new direction for the magazine. The publication offices have been moved — and in late December 1981, our team of people in Peterborough began work on the creation of a new and vigorous magazine for the modern intelligent machine experimenter.

Beginning with this January/February 1982 issue, Robotics Age has moved its offices to Peterborough, N.H. The new address and telephone contact information is:

Robotics Age
174 Concord Street
Peterborough, N.H. 03458 (603) 924-7136

A number of staffing changes are reflected on the masthead, largely dictated by the expense of moving people from a West Coast location to an East Coast location. The people who have until now provided first a quarterly, then a bi-monthly Robotics Age since the summer of 1979 will remain in Los Angeles, working on the Robotics Industry Directory and other products published by Phil's company, Technical Database Corporation.

The people we have assembled to produce Robotics Age in Peterborough represent the best and most talented people in a region which is to high technology publishing what the Santa Clara valley is to silicon electronics manufacturing. I have personally worked with and known many of them for several years. We will initially continue the bi-monthly frequency of publication which Robotics Age started in 1981.

During the coming months of 1982, readers will see a number of significant alterations in Robotics Age. Various details of the internal format and editorial content will change as we build a new and more vital, interactive magazine. We will continue to place considerable emphasis on the general field of robotics applications: computer aided design and computer aided manufacturing. Our strong and practical theoretical discussions of the important software, engineering, and scientific questions in systems design and applications is one of the most exciting areas of our editorial territory.

There will be a continued emphasis on the technology and techniques for experimentation and implementation of robotic systems. The tools and products we talk about will range from inexpensive, personally owned computers, robot arms, and machine shop equipment, to the sophisticated computer aided design, graphic design, and artificial intelligence equipment now coming to the market. Whether the designing is done by professionals, educators teaching new professionals, or simply by amateurs with personal computers and conventional home workshop tools, it contributes to the growth of the field. We've seen this same phenomenon earlier in the eras of automotive and aviation pioneering, radio pioneering, and recently in personal computing.

The amateur in robotics is an important and vital link in the chain of events needed to train competent robotics engineers for the coming decades. The technologist who builds to a personal budget while exploring the problems of the field has proved to be a vital force in previous eras of innovation. Whether it is a Steve Jobs or Steve Wozniak of Apple Computer fame, or, in a different era, a Henry Ford, the spark of innovation in technology is an individual matter. A truly professional technological innovator does not turn off his or her mind upon leaving the official place of work. As in past eras, new companies starting with new ideas often spring from the workshop of the amateur — who has already become the true professional through love of his work.

Advertising will grow during the coming months, both in quantity and in the breadth of companies supporting this unique forum. And, as the circulation and advertising expand, readers will see increasing editorial content with many new and exciting articles about concepts of intelligent machine system designs.

*From The Nine Nations of North America by Joel Garreau, page 42. Published by Houghton Mifflin Company, Boston, 1981.

Letters

Additions to "The Robot Builder's Bookshelf"

The September/October issue of *Robotics Age* contained a book list, "The Robot Builders Bookshelf," submitted by David Smith and Mike Schoonmaker. I would like to suggest the following additions:

Robotics, by John F. Young, John Wiley & Sons, 1973. This is a fine introduction to the varied physical considerations in designing robots. The book contains chapters on senses, actuation, mobility, manipulation, vision, proprioception, hearing, and speech. Of particular value are the numerous references with which each chapter is concluded. *Robotics* is written as a technical survey for the educated robotics researcher, i.e., mathematical, electronic, and control theory concepts are used.

Teleoperators and Human Augmentation, by Edwin G. Johnsen and William R. Corliss, AEC-NASA Technology Survey, NASA SP5047, 1967.

Teleoperator Controls, by William R. Corliss and Edwin G. Johnsen, AEC-NASA Technology Survey, NASA SP-5070, 1970.

Advancements in Teleoperator Systems, University of Denver Colloquium, AEC-NASA Technology Utilization Publication, NASA SP-5081, 1970.

The three NASA publications provide an excellent summary of the work done in teleoperator design up to 1970. Much of this work formed the basis of the robotics research carried out through the 70's. Publications SP-5047 and SP-5070 are particularly useful as overviews, whereas SP-5081 is essentially a transcription of a colloquium held at the University of Denver. (I imagine, by content and association, that these books were the basis of Johnsen and Cor-

liss' 1971 book *Human Factors and Applications in Teleoperator Design and Operation*.) These books were still available from the National Technical Information Service, Springfield, VA 22161 as of February 1981.

I will also take this opportunity to congratulate you on seeing the need for such a magazine as *Robotics Age* and for acting on that vision. I have been a reader since it first appeared, and, finally convinced of your continued seriousness in approaching this subject, have recently become a subscriber. I hope to see your efforts continue.

Craig W. Heckathorne
156 Asbury Ave., Apt. 10
Evanston, IL 60202

Praise for Robotics Age

Of necessity, I read many industry magazines, both related and unrelated to automatic manipulation devices. I find your experimenter-oriented teaching format excellent in every way. By stressing lower cost solutions to problems previously relegated to the research capability of a mega-buck style science fiction fantasy, your magazine has provided itself with a much larger audience.

Friends and associates who are not in technical fields have paid compliments to your publication's graphics, lucid and comprehensive writing, and have told me that they would like to see articles in your format style done in publications of their interests.

Great work.

W. Drohsler
124 Cypress St.
Westwood, NJ 07675

Incredible Hulk Android

I have found the Holy Grail! Well, not really, However, I did discover another source for motorized wheels

and gel cell batteries. After calling several surplus houses, I found that motorized wheels are scarce. This news almost crippled my android. Fortunately, I found the Hulk electric car manufactured by Empire Toys. It includes a motorized wheel, 6V, 8 amp-hour gell cell, and recharger. More importantly it costs less than \$25. Although the gearbox assembly is plastic, the wheel is quite sturdy.

My android now uses two motorized wheels and four gel cells. I hope others find this toy useful.

Michael A. Tyborski
5937 Sugarbush Lane
Greendale, WI 53129

Many of today's toys can provide ready supplies of robot parts. We are interested in hearing from anyone using toys as a basis for robots. Ed.

New Robotics Courses

The Department of Industrial Engineering at New Mexico State University has recently added two new courses on robotics and computer-aided manufacturing to its curriculum. IE 481 covers such basics as microprocessors, real-time control, digital simulation fundamentals, and control theory. A follow-up course, IE 482, emphasizes fundamentals of robot design, programming and control systems, and integrating robots into full-scale computer-aided manufacturing systems. Included are topics dealing with hierarchial and supervisory control, computer-aided design, robot-based workcells, group technology, and economic feasibility analyses.

The accompanying labs have four robot manipulators — two hobbyist, one industrial, and one designed in-house. The manipulators are controlled by two S-100 CP/M-based microcomputers, an 8-bit 6 MHz Z-80-B system, and a 16-bit 8088 system with 256K bytes of memory.

Letters

Both systems have high-resolution color graphics and a high-resolution video digitizer for robot vision research. The robot arms are part of a much larger production system using a scaled-down physical simulation system purchased from Fisher-Werke of West Germany.

We feel that these courses and labs, together with the balance of the curriculum, provide our students with the necessary exposure to modern automation systems needed to keep current with advancing technologies in industry.

Michael W. Burke
Assistant Professor
New Mexico State University
College of Engineering
Box 4230
Las Cruces, NM 88003

More University Robotics Research Groups

There are three areas of robotics research going on at Rensselaer Polytechnic Institute. You have previously mentioned (September/October 1981, Letters) Dr. G. Saridis who works with Dr. K. Shin in the area of artificial intelligence, vision, and control. I head up another robotic concern, namely geometry and kinematics, and have a simulation program, GRASP (General Robot Arm Simulation Program), that uses a computer graphics display to model almost any robot arm, its hand, and environment. We are currently evaluating new designs for several outside interests. The Center for Manufacturing Productivity at RPI is concerned with robot safety and specific applications.

Dr. Stephen Derby
Rensselaer Polytechnic Institute
Troy, NY 12181

Call for Papers: AAAI

The American Association for Artificial Intelligence has issued a call for papers to be presented at the August 18 through 20, 1982 convention at The University of Pittsburgh and Carnegie-Mellon University, Pittsburgh, PA. Some of the topics to be covered include: knowledge representation, cognitive modeling, knowledge acquisition, problem solving and search, program synthesis and understanding, AI languages and software, specialized architectures for AI, vision, robotics, applications systems, and game playing.

Four copies of a short paper (1,000 to 2,000 words) should be sent by April 15, 1982 to: David Waltz, AAAI Program Chairman, Coordinated Science Laboratory, University of Illinois, 1101 West

Springfield, Urbana IL 61801. Authors will be notified by May 15, 1982 of acceptance or rejection.

Call For Papers

Authors are invited to submit research or tutorial papers on aspects of circuit and system theory, communications, robotics, analog and digital signal processing, or computer-aided design for presentation at the 25th Midwest Symposium on Circuits and Systems to be held on August 30 and 31, 1982 at the Michigan Technological University. Authors should submit, in duplicate, a 300-word summary of their contribution prior to April 17 to Professor Paul Lewis, Co-chairman; Dr. R. Eugene Stuffle, Co-chairman; Department of Electrical Engineering, Michigan Technological University, Houghton, MI 49931.



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Infoworld, December 21, 1981. *Infoworld* has described a "Chess Robot Adversary" that will be available in January from the New York gift store Hammacher Schlemmer. Priced at \$1300, the Adversary is certified by the U. S. Chess Federation.

As described, the game is controlled by a 24K-byte program called "Mychess," developed in Hong Kong by Novag Industries, Ltd. After each move, the built-in robot arm moves the Adversary's chosen piece. In addition, the Adversary removes the pieces it captures and resets the pieces to their original position at the end of each game.

A CMOS memory enables the Adversary to store an interrupted game for up to three months. Ten levels of skill are available and all international chess rules are followed. Standard tournament timing is used on levels four and five. Accessories include a travel bag for \$150, a hard-copy printer for \$165, and a quartz chess clock that retails for \$145.

Omi, January 1982. "Japan reaches for a future world. . ."

Weighing about 130 kilograms, the easily disassembled robot has the appearance of a "benign metallic Frankenstein monster." But despite its inhuman looks, the robot's creator treats it like part of the family — witness his home movies.

The pictures, as described in *Omi*, were taken by Ichiro Kato of the Waseda University, and they chronicle the early life of "Wabot": first steps taking 110 seconds, later cover-

ing the same ground in nine seconds. As Wabot moves its upper torso, Kato, chairman of the Waseda Graduate School of Science and Engineering proclaims, "There you have a one-and-a-half-year-old toddler." Kato is further quoted as saying, "When a child becomes seven years old, he has an ability equal to the adult. My goal is to build a robot that will have a seven-year-old's ability."

Kato predicts that robots of the twenty-first century will be very different from the rivet-punching drones of today. "The industrial robot today is the mainstay of all robots. They are simply laborers or function oriented. But in the next twenty years we will witness the emergence of the robot in service areas such as medicine. The robot will take over in everyday situations and will closely resemble human beings, with the integration of artificial intelligence, voice, tactile recognition, and bodily functions. Through this mechanization of the human being, we will know more about ourselves. And to know yourself is the long pursuit."

In the fourteen years since it imported an American-made industrial robot, Japan has emerged as the robot center of the world with almost 70% of the world robot population — more than 77,000 industrial robots. And having spent nearly \$3 billion on robotization in 1980, Japanese experts predict that the total investment will be at least 12 times as much in three more years.

Japanese futurists are described as being quite smug about turning robots loose on the street. "In Japan we have a tradition of having things

similar to slaves in the village, such as a horse and a cow," comments science-fiction writer and future planner Sakyo Komatsu. "These were considered a part of the family. When machines such as the automobile and electric trains were introduced into Japan, they were considered living creatures. Even in the village today, especially during the New Year celebration, you can see cars being decorated with paper ornaments. So, for the Japanese, to witness this emerging of robots is like watching small children who are there to help their parents."

A Tokyo television station, NHK, broadcast a typical robot success story about a mom-and-pop manufacturing firm. In the face of bankruptcy due to the cost of labor, two robots were rented, and the owner's son was hired back from a job in Tokyo to help automate the plant. In a switch on Alvin Toffler's electronic cottage industry idea, the family was reunited, the business showed a profit, and the mother liked the robots because she didn't have to serve them tea all the time.

While American blue collar workers are fearful of losing jobs to robots and automation, the problem is considered less severe in Japan because an increasing number of young Japanese are entering college and heading for white collar professions. By 1985 an estimated 60% of the Japanese work force will be in service- or information-oriented industries, not production work. This is further supported by Japanese government estimates that already some 840,000 skilled workers are

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needed, mostly in small enterprises.

It's anticipated that the robots will take many forms. One, a snakelike robot, will be able to grasp objects of any hardness or shape. Called the "soft gripper," it could be used by the Tokyo Fire Department to rescue people from burning buildings. Another robot, shaped like a spider, uses a rapid-fire low-power laser for a sensory system to guide its movements. The next generation spider will carry 20 kilograms, and Dr. Shigeo Hirose of the Tokyo Institute of Technology, the creator of these odd-shaped devices, predicts that the robot may ultimately replace the baby carriage.

"There is a constant theme in science fiction that robots will destroy human beings," muses Kato. "They do so only at the point when they acquire emotion. If I consider emotion part of intelligence, then I don't think we can build a robot with equal ability. But for now, the more versatile a robot becomes, the more it resembles a human in shape.

"When we come to a service robot, the shape will have to be similar to that of a human being. In the case of the factory, you can lay out the plant in such a way as to make it suitable to the working conditions of the robot. But when robots come into our houses, then it really should be the other way around."

Money Magazine, December, 1981. *Money Magazine* notes that two major robot manufacturers have recently become public companies. Until lately, no company whose sole pur-

pose was the production and design of robots has been available for public investing. In late October, Condec announced a 20% stock offering of Unimation, their robotics subsidiary whose annual sales of \$56 million accounts for 40% of the U.S. robot market. The stock offering of 925,000 shares planned for late November was expected to range from \$19 to \$23 per share traded over the counter.

New Issues, a Florida-based advisory service, was quoted as considering the proposed offering price high, based on Unimation's earnings for fiscal year 1981 of \$0.48 per share, and the service pointed out that Unimation's profit record to date is erratic. Editor Norman Fosback adds, "Unimation enjoys the dominant position in an exciting growth industry. I'd rate the stock an attractive long-term investment at a price of around \$18."

Another company involved in robot production, Prab, made a public offering in September at \$10 per share and was recently traded over the counter at \$15. Metal recycling systems and conveying equipment not involving robots still account for 55% of Prab's revenue. Earnings for the nine month period ending July 31 were \$0.44 per share. Fosback believes that Prab stock would be a good buy if it drops to the \$10 level.

The Wall Street Journal, January 8, 1982. A recent article in *The Wall Street Journal* describes the growing interest with which industry is watching the development of conducting

plastics, also known as synthetic metals and conducting polymers. A major advantage of plastics is the potential cost savings over more expensive metals. The plastics might be used to make cheap solar cells, semiconductors, and even replace some wiring. "If you had a stable conducting plastic, the number of uses people would ferret out would be astonishing," says Bryan Street, manager of an IBM group studying conducting plastics.

The plastics are chemically or electrochemically modified to make them capable of electrical conducting. This modification leaves them susceptible to deterioration when exposed to air or moisture. To circumvent this present susceptibility, the plastics will probably first be hermetically sealed within batteries. Alan McDiarmid of the University of Pennsylvania claims that plastic batteries can store two to three times as much energy as lead-acid batteries weighing the same amount, give up the stored energy 25 times faster, and charge faster than a comparable lead-acid battery. Barring unforeseen problems, we may see plastic batteries in the next 10 years.

A "blue sky" area of speculation about conducting polymers is their potential for superconductors. Creating a conducting polymer that becomes a superconductor at room temperature would be the equivalent of "finding the Holy Grail," says McDiarmid. It's not so far out that people don't discuss it seriously at scientific meetings.

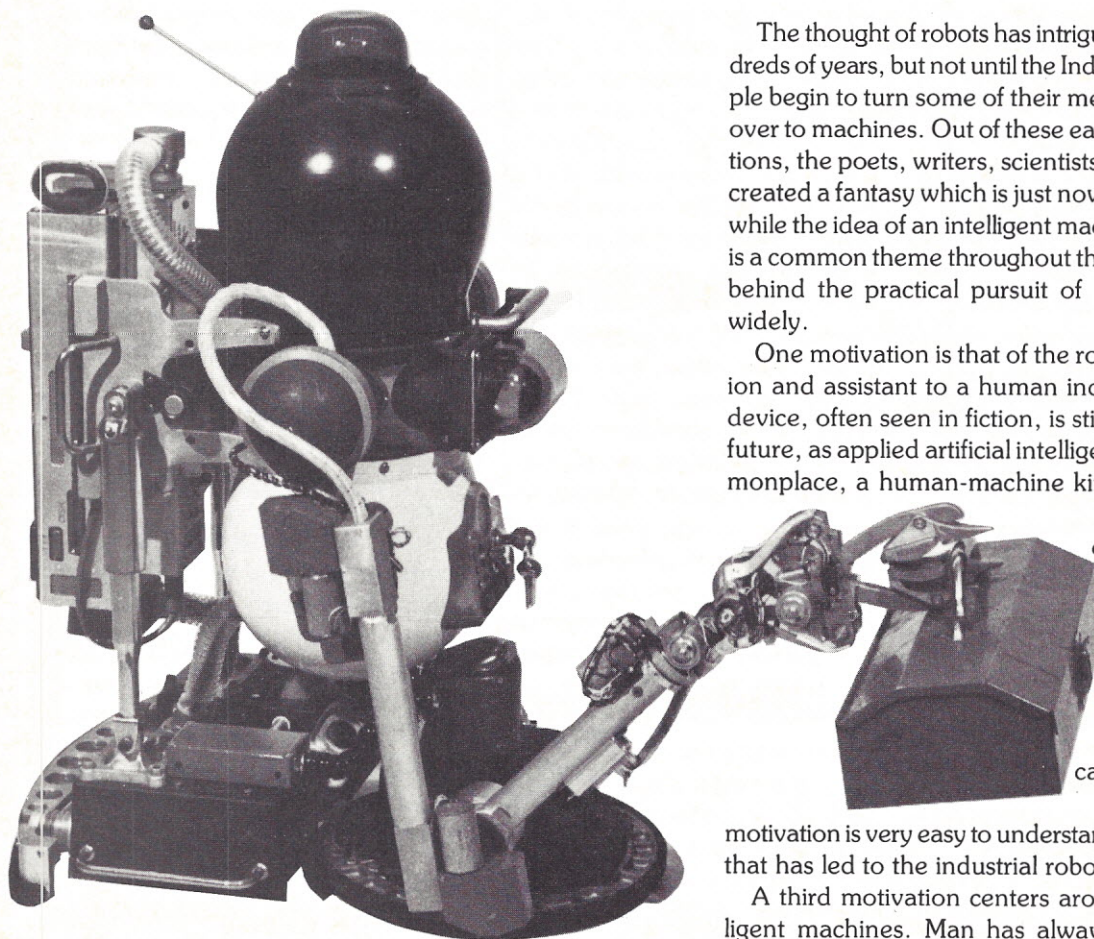
AVATAR: A HOMEBUILT ROBOT

by Charles Balmer, Jr.

929 South Dugan Road

Urbana, Ohio 43078

Photo 1. Carrying out the fantasy of the helpful personal companion, Avatar is shown delivering a tool box to his master.



Last year, *Robotics Age* ran a "Homebuilt Robot Photo Contest" with the goal of drawing out photos — and articles — about the experimental robot systems many of our readers are building. Of the entries received by the October 1, 1981 deadline, Avatar by Charles Balmer Jr. was the clear winner by virtue of system concept, descriptive material in the form of this article, and excellent photographs, one of which, taken in color, provides the cover illustration for this issue. The cover photograph and all photos accompanying this article were taken by the author.

Perspectives on Robots

The thought of robots has intrigued man for probably hundreds of years, but not until the Industrial Revolution did people begin to turn some of their mental and physical abilities over to machines. Out of these earliest mechanical contraptions, the poets, writers, scientists, and other men of vision created a fantasy which is just now becoming a reality. And while the idea of an intelligent machine companion or robot is a common theme throughout the fantasy, the motivations behind the practical pursuit of the robotics dream vary widely.

One motivation is that of the robot who is both companion and assistant to a human individual. The companion device, often seen in fiction, is still mostly a fantasy. In the future, as applied artificial intelligence becomes more commonplace, a human-machine kinship similar to that of a captain and his ship, or even of a human and his dog may develop.

A second motivation is the practical desire for a worker robot, one who will amplify our production capability with a minimum of human effort. This motivation is very easy to understand and it is the driving force that has led to the industrial robots existing today.

A third motivation centers around the building of intelligent machines. Man has always desired to understand

his own intelligence, and that understanding would imply the ability to duplicate, change, and expand. Although the intelligence of today's machines is very low, some experimental machines in the artificial intelligence laboratories are beginning to show glimmers of intelligence that may blossom, guiding us to the next plateau in our understanding of both man and machine.

Many roboticists like myself tend to work in relative isolation, occasionally going public partly because of pride in our accomplishments. This urge is also due to a desire to share some of what we have learned, to learn what others are willing to share, and maybe even to inspire greater accomplishments. While our interest in robots separates us as a group, it is that same common interest which binds us together in the pursuit of a dream. Our job as experimenters or researchers is to take the robot fantasy and turn it into a robot reality.

Setting Some Goals

The robot designer and builder have some pretty tough decisions to make throughout the project, but the hardest ones must be faced at the start. What's it going to look like? How big is it going to be? How is it going to be powered? What computer is it going to use? And, the most difficult question, what is it going to do? It's interesting to note that whenever you mention to someone that you're building a robot, they inevitably ask the most difficult question first. Don't be afraid to say "I don't know yet."

While many of the detailed questions are going to depend on the individual project, here are several suggestions that will help guide the initial planning.

General Purpose Modular Designs Are Attractive

Very few homebuilt robots are going to be designed to perform only one task. At some point in the future you will want to add or change something. This means that flexibility and modularity should be prime considerations in your design. In short, the design should have a general-purpose flavor.

Think of your robot as a testbed or a laboratory in which you are going to conduct both practical and entertaining ex-

periments. You may want to try different navigation programs or add a new type of sensor to make its hand sensitive to touch. These and other additions can be accommodated if the robot laboratory environment is preserved.

Another general guideline is to design a fully integrated robot system. Since the robot is going to be computer controlled, the real flexibility is in the software, so provisions must be made for programming the robot directly or loading the program into the robot after it has been generated on another machine. Both approaches have advantages and disadvantages, but the important thing to remember is that you are building a *system*. This means designing well-defined and segmented modules and, most important, well defined and easy-to-use mechanical and electrical interfaces between modules. The basic components of an integrated system are a computer, a mass storage device for program storage, a terminal or console, and a printer for hardcopy generation. Provisions should also be made so that your programs can be run and debugged in the robot's computer system. With all of these things "designed-in" from the start your robot lab will be usable as soon as you can turn on the computer.

Cautions

There are two cautions I would like to mention. First, don't attempt a design that is too ambitious — if your robot lab is designed properly, you will be able to expand its capabilities as time goes on. Remember there are a number of limitations you must contend with throughout the project. The most damaging are the lack of money, time, technology, and your own abilities. Any one of these deficiencies can doom a project before it is started.

The second caution may not seem major, but what you decide will greatly influence what you can expect from the project. If you choose the robot lab approach, you will be all set to experiment with many different areas of robotics. The

Charles Balmer Jr. is currently manager of the Software Engineering Department for United Systems Corporation, where he has worked for the last six years. Prior to that he worked in the Bionics Branch at Wright-Patterson Air Force Base, investigating the problems of adaptive computer systems. He has built several smaller self propelled robots over the past 15 years.

other approach is to build a system which does some very limited or practical task. In this case you will probably dedicate your robot with no intention of modifying what it does. Take a hard look at what you want to accomplish and choose the approach that fits your needs.

The final comment concerns the actual construction, and is strictly a personal observation. A robot is a three dimensional, functional, but imaginative sculpture. One of the great pleasures in designing and building a robot is to let your imagination run wild (not amuck). You quickly learn to balance practicality and form to produce something that not only does the job but also satisfies the craftsman's sense of perfection and the artist's sense of shape. The form need not be humanoid although people will treat it with more understanding if they can identify some human structural or functional qualities.

The robot's shape will be greatly influenced by the task, sensor capability, center of gravity, terrain, environment, etc. Some people find the exposed electronics and mechanics intriguing, while others prefer everything to be enclosed. In any case, the appearance of the robot is going to affect everyone differently, but the quality of the workmanship

should always leave a good impression. Remember, your robot is you.

The Naming of a Robot: *Avatar*

A robot is somewhat like a child. It requires a great deal of patience, time and energy to construct, and then as it limps and crashes and smokes its way to adulthood, we as mothers and fathers learn something about being a robot while hopefully our robot learns a little bit about being a human. It seems only natural then that it should have a name, if for no other reason than to have something to yell during a fit of frustration or anger. I chose Avatar, the name of a mythical character in the movie *Wizards*, over several other equally "meaningful" names simply because it was phonetically richer. This is important because the robot has a voice input command system which I will discuss later in more detail.

Before elaborating on the specific capabilities of Avatar it should be noted that some are not yet fully designed or im-

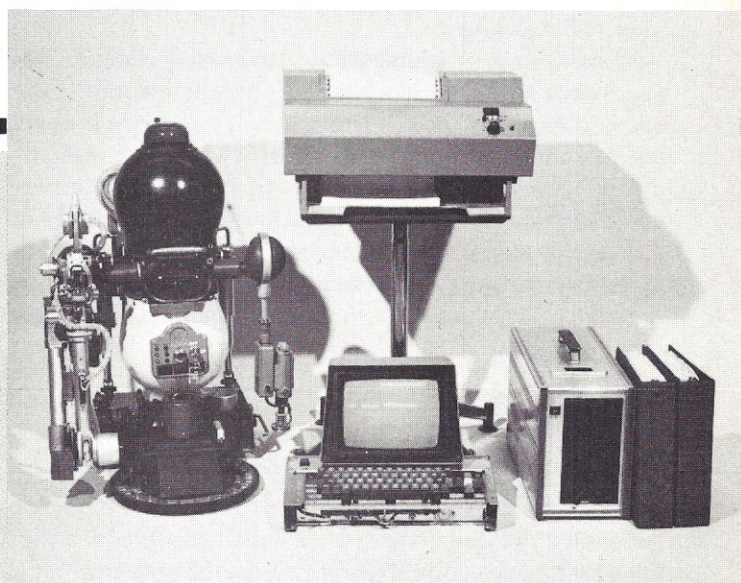
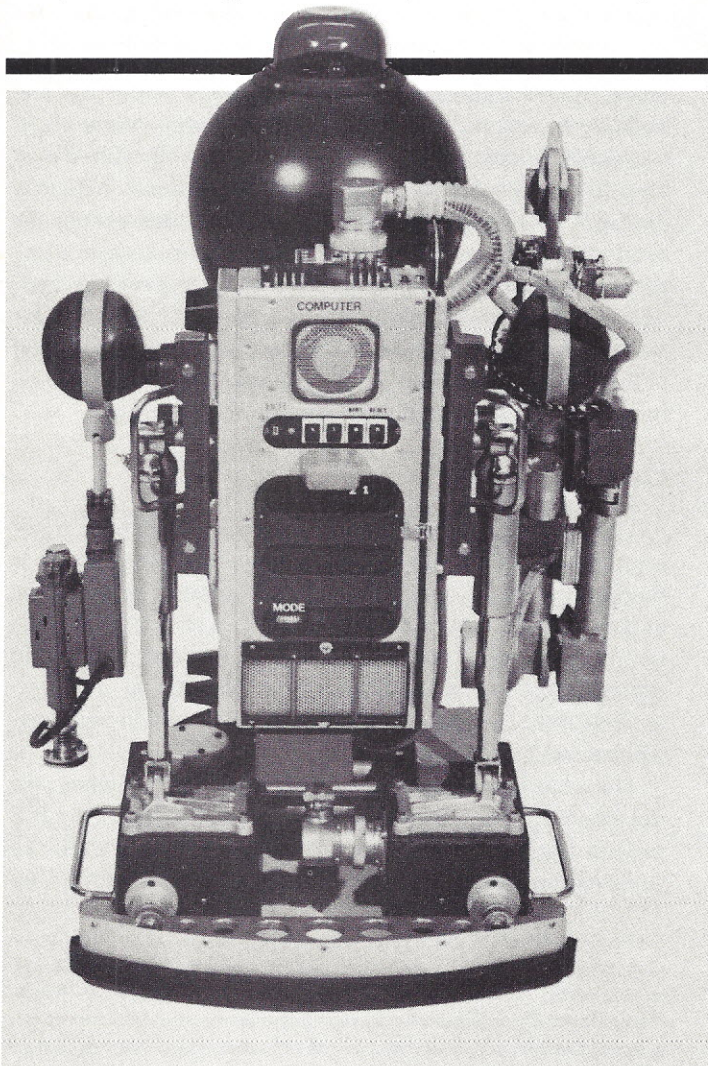


Photo 2. In the rear view, at left, the manipulator arm is on the right and the battery recharging Oasis access is on the left. The rear panel consists of the on-board computer's indicators behind a red plastic filter and switches for boot load and system reset.

Photo 3. Above, the complete Avatar development laboratory. As a robot, Avatar is an autonomous mobile device. But its on-

board 64K byte 8085 processor needs much more in order to be used as a CP/M-based single-board computer (SBC) development system. Extra hardware includes a line printer (center, top), a home built video terminal (center, bottom), and a floppy disk drive. When used as a development system, Avatar's on-board computer is connected to these other system components and all drive power is removed to prevent accidents.

plemented. This is to be expected since Avatar is a laboratory and may never be totally finished.

My initial goals for the testbed design were, in the order of their priority:

1. To have a fully integrated system.
 - a. Robot computer doubles as a software development system.
 - b. Computer peripherals include two 8-inch single density disk drives, a video terminal and an 80-column dot matrix printer.
 - c. All system software can be debugged in the robot using a system monitor program and a tether cable to the video terminal.
2. System will respond to voice input commands and possess a minimal voice output capability.
3. Robot will be able to navigate in a flat environment.
4. Robot will be able to locate and connect to a battery recharge station called an "oasis."

Currently, goals 1 and 2 are complete while 3 and 4 are only partially done.

In addition to this list of formal goals, an arm with six degrees of freedom was built, mostly for the fun of it, and some primitive software has been designed which will provide macro instruction capability for doing real-time coordinated movements. (As of this writing, the arm hasn't been tested because of lack of time.)

Goal 1, while complex, was achieved in a relatively straightforward manner. It took about one and a half years to build the three computer boards and the enclosure, the video terminal, the disk system, and the printer. Once these were finished and the operating system installed, I was able to begin software development. My initial tasks were to build a real-time executive and a command interpreter. As things progressed it was easy to add new software modules as I finished them.

Goal 2 was partially realized by purchasing a commercial speech synthesizer and interfacing it to the computer. A little driver software and I had voice output with a vocabulary of about 400 words in less than a month. The speech recognition portion of goal 2 was not accomplished so easily. The hardware design was not too difficult, taking only a few months. The speech recognition software development has

A

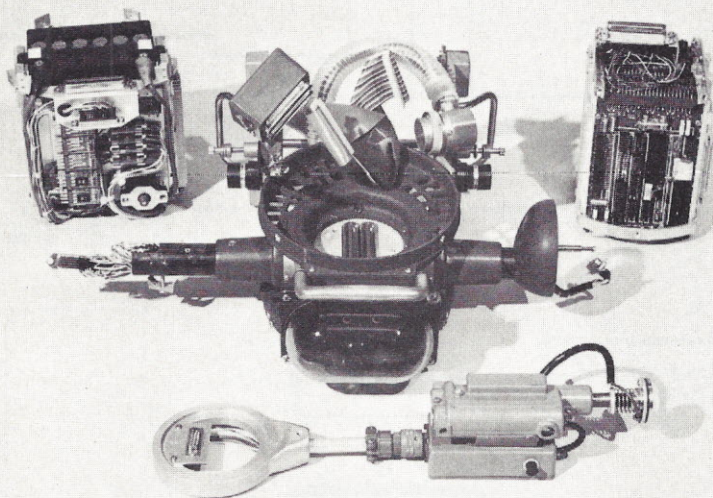
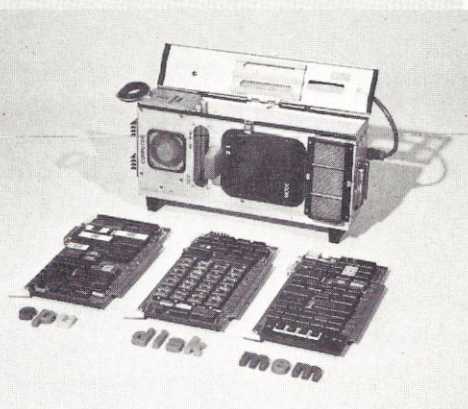


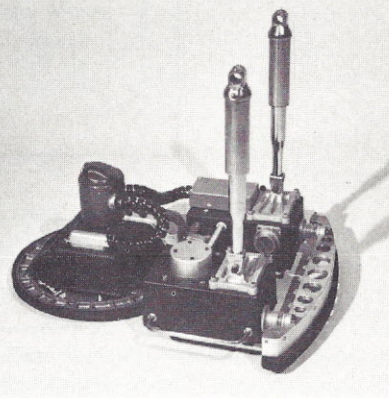
Photo 4. In this sequence of photos we show several views of Avatar in various stages of disassembly. At (a) we show the central body parts of Avatar including the power chassis (left), trunk structure (middle) and upper chassis (right). The computer chassis assembly (b) mounts in back of the trunk structure

of Avatar. The base of the robot is a tractor assembly consisting of a powered steering wheel and two unpowered wheels (c). Note that the entire structure is designed for quick assembly and disassembly, a must for ease of service.

B



C



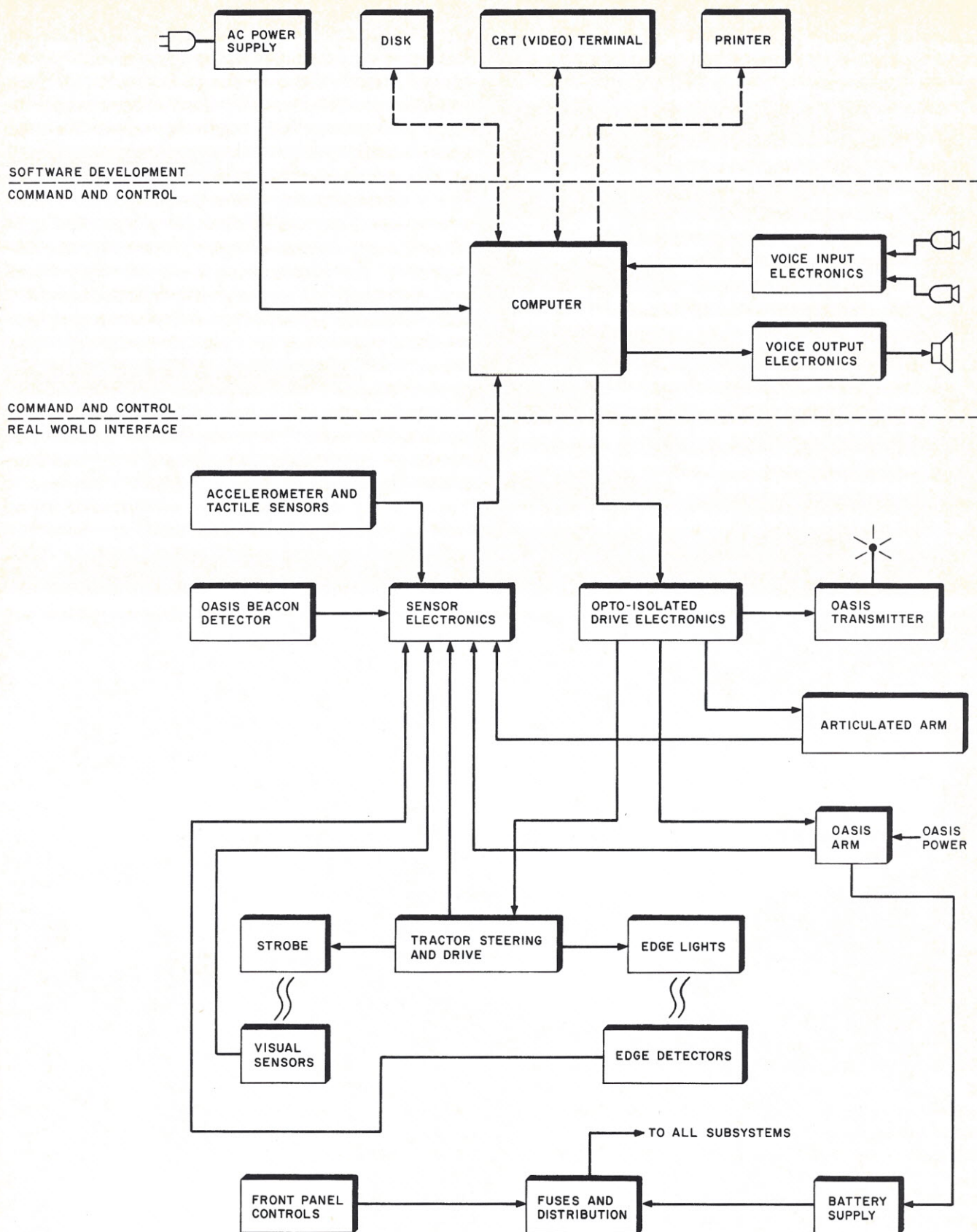


Figure 1. The Avatar robotics experimental system can be viewed as three major portions. At the bottom of this drawing we see the real-world interfaces, comprising the bulk of the diagram. In the middle we see command and control portions, principally, a computer with voice input and output. Finally, there is auxiliary software development hardware and software including a disk system, printer, terminal, and software tools.

taken about a year, but it has been worth it. Though the vocabulary is limited to about 30 words, this is quite adequate for most anticipated uses. The system is basically a speaker-dependent, isolated-word recognizer, but it can be easily trained to several speakers and even identify which one is talking.

Goal 3 is currently in progress. Most of the mechanical system is complete and functional. Some additional work must be done on the data acquisition section which brings all of the analog and digital signals from the sensors into the computer. While the basic motor drive software has been designed, it has not been fully tested. Motor speed and direction control is provided on a real-time basis directly from the computer using pulse width modulated speed control to the motors. Because it is all digital, the drive transistors dissipate a minimal amount of power.

A robot must be able to resolve its environment at least to within its own dimensions if it is going to successfully navigate. The ability to resolve is a function of the sensory systems and their ability to detect objects, walls, doors, steps down, etc. If you watch a very small insect navigate on a flat surface with obstacles in its way, you will notice that the old

"crash and turn" method of navigation is an effective mechanism for getting about. For robots, however, which can weigh tens or hundreds of pounds, this method should be used as a last resort, unless you like damaged furniture and bruises.

Some method of non-contact object detection is a must. I chose to use the reflected light from the flash of a strobe. With four detectors mounted in a proper relationship to the strobe it is possible to build a crude but effective object sensor that will avoid collisions with large objects. As a backup however, the tractor is equipped with bump sensors and a four quadrant accelerometer to detect bumps on parts of the structure with no sensors. Another group of detectors sense holes or steps in the floor. This prevents the robot from sneaking through an open door and careening down the basement stairs. The drop-off sensors are also reflective and mounted ahead of and behind the wheels to sense when there is a sudden change in floor height. All of these sensors plus a navigation program capable of remembering its environment will, I hope, prove effective. The basic robot hardware block diagram is shown in Figure 1. Table 1 summarizes the system in more complete detail.

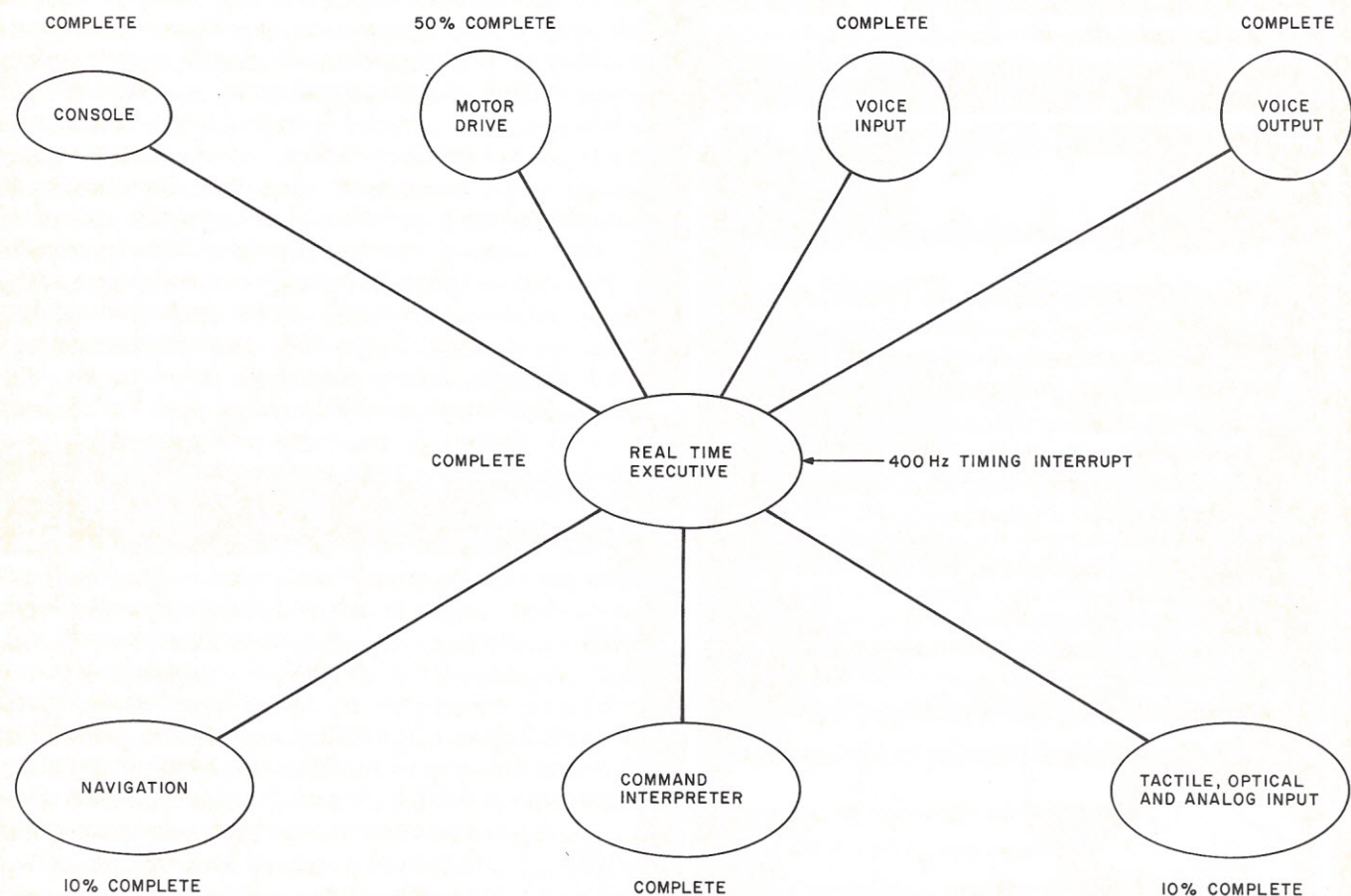


Figure 2. Avatar is controlled by a real-time software system running in its on-board 8085 computer module with 64K bytes of memory. This real-time software executes from a 400 Hz (2.5 ms period) interrupt clock. Software development tools including the CP/M disk operating system and compilers are not shown here.

Goal 4 addresses the problem of recharging the batteries as the robot wanders about. I suppose the robot could be designed to plug itself into a wall outlet, but I wouldn't be too comfortable knowing that it was wandering around trying to plug itself into a 120 V AC outlet. And I'd sleep better if I knew that its source of power had built-in safeguards to prevent or protect against shorts, sparks, overcharging, etc.

This concern led me to adopt the "oasis" concept. An oasis is a low voltage charging station with a beacon that can be activated by the robot when its batteries get low. The robot

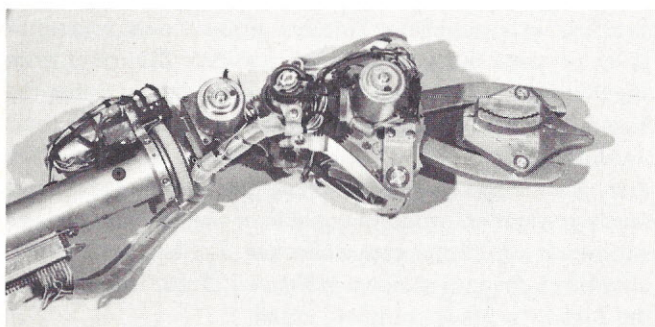


Photo 5. The hand of Avatar. This view details the end of Avatar's manipulator arm and its hand. The hand and arm has six degrees of freedom for complete control over its position in 3-space.

will have to remember how to get back to the oasis, but once there it can activate the beacon and maneuver itself into the proper position. The main beacon and another smaller beacon guide the robot into the charging station where it merely plugs itself into a special self-aligning socket and starts a recharge cycle. Once the recharge is complete, it will be free to move again.

A Word About Software Development

The computer software includes a disk operating system for managing the information stored on the disks, an assembler and an editor. High level languages which will run on the system include Basic, Fortran, Pascal and others. These along with many utility programs provide all the software development power that is needed. The system software for the robot itself is composed of several functional modules, all run under the supervision of a realtime executive. A simplified task diagram is shown in Figure 2. This diagram also shows a summary of progress to date.

A Word About The Structure Of Avatar

The mechanical structure is made from both surplus and specially designed and fabricated parts. The body domes are spun steel covers from an old x-ray unit, while most of the internal structure was constructed from aluminum bar stock. The computer supports are specially designed aluminum castings made in my foundry. The tractor assembly contains nine specially designed castings, while the arm contains eight more. Most of the gear reducers were surplus; however, the gear reducer and chain drive to the front wheel were completely fabricated. The computer enclosure was built from aluminum sheet metal and was designed to be easily removed from the robot chassis for service or stand alone use. Overall I have spent about 30% of my time designing and building the mechanical structure and 30% of my time designing and building the electronics. The software design time accounted for the balance of 40%.

Conclusion

The Avatar project has already stretched over four years and it is still going strong. I hope that within another year I will have achieved my four initial goals and will be able to choose some new ones. I have learned more from this project than I ever expected. I think I still have a lot left to learn. The most satisfying part of the project has been the voice recognition system since it had the most unknowns associated with it. After reading many books and experimenting with different techniques, I was able to make it work.

I would not recommend starting a robot construction project of this size unless your dream is strong, because without that emotional motivation you will not have enough momentum to overcome some of the obstacles. But if you can stay with it, it will probably be one of the most satisfying things you ever do. ■

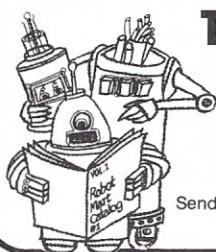
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Visual and Edge Sense Electronics
Oasis Transmitter and Antenna

Trunk

Red Glass on Trunk Covers the 4 Sector
Visual Non-Contact Obstacle Detector Using
Light From Forward Looking Strobe Mounted
In Steering Pod On Tractor

Lower Torso

Battery
Fuses and Circuit Breakers
Edge Light Flasher
Power Distribution and Control Relays
Front Panel Controls
1) 3 Position Keylock
A) Off
B) Computer Only
C) Computer and Auxiliary Systems
2) Red Button Controls Power To Tractor
3) Yellow Button Controls Power To Arm
4) Green Button Is a Spare
5) Yellow LED Indicates Power Supplied From
Computer AC Supply
6) Top Red LED Indicates Battery Charged
7) Next Red LED Indicates Keyswitch Is On
8) Other 3 LEDs Are Spares
9) Volume Control Is For Voice Output
10) Grill Covers Voice Output Speaker

Left (Power Recharge) Arm

Fixed Position
Extension To Plug Into Oasis Recharge Station

Right Manipulator Arm

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Gripper Style Hand
Analog Position Feedback

Tractor

Tricycle Front Wheel Power and Steering With
Bumper Ring Sensor
Reflective Edge Sensors
Strobe Power Supply and Light
4 Quadrant Bump Sensor

Physical Characteristics

Weight 85 Lbs. (39 kg)
Height 30" (76cm)
Width 21" (53 cm)
Depth (Arm Retracted) 22" (56 cm)
Max Run Time On Battery 1.5 Hours

Table 1. Specifications of Avatar. The robot is a complex system of many interrelated subsystems. Part numbers are shown for computer hardware components where applicable.

A LOOK AT SS-50 COMPUTER BOARDS

by David Smith
4505 Kennedy Blvd
N. Bergen, New Jersey 07047

After considering a variety of approaches to providing my robot design with an on-board computer I decided on the 6800 processor and the SS-50 bus system. I have been looking into the 6802 and 6809 processors and will take a look at the 68000 when I can.

I'm not going to claim that my choice of processor and bus is the best combination for a robot; it just happens that my home system is a 6800 on an SS-50 bus and after looking at the other buses and processors I decided to stick with what I already had.

I started out with the idea of a fixed base computer linked to the robot by radio or other types of remote control. This design would have far more bulk storage, be far more complex, and be safer from accidents than an on-board computer.

However, the FCC has a regulation against unattended radio transmitters. Legally, this means that you can transmit to a robot but the robot cannot use a transmitter to send data back, even if it is only 100 milliwatts.

This may be a blessing in disguise as there is very little free space in the radio spectrum anyway, and no part of the spectrum that is free from interference and range problems. However, as I looked into the bandwidth requirements and the error rate and range limits I finally decided to use an on-board computer.

I also decided to use ready-made boards instead of home brewing a system since I did not want to spend much time wirewrapping and debugging a new system. By using standard, prebuilt boards or kits whenever possible I can be sure my local computer store or the manufacturer can provide services. By not homebrewing the system, I can swap the boards used between systems, and if I decide to abandon the robot project the boards that I don't reuse have a much higher resale value than a homebrew board. Using standard boards also means that a large number of people have the same board and are busy writing software, coming up with modifications, new uses, and finding and fixing bugs. This extra help is well

worth the money, particularly if you are unskilled in building and debugging hardware.

After ruling out a homebrew system I decided on the SS-50 bus for several reasons. The SS-50 bus is popular (more than five manufacturers offer mainframes and boards), and a number of other manufacturers provide a wide choice of boards and accessories.

The SS-50 bus uses low-cost Molex pins which provide good mechanical and electrical connections. These pins are easy to replace if any are damaged. The traces are well spaced and thick, offering low inductance and low capacitive coupling. The bus line functions are standard throughout the industry, and there is a wide selection of cards and mainframes to chose from.

SS-50 Bus Products

The list that accompanies this article is provided for your convenience and should not be taken as an endorsement. Likewise, the failure of a product or company to appear on this list is not intended as a comment.

Also, please note that the suitability of a product often depends on both the skill of the user and the application. Some hardware may require that the user write software, or a software package may have to be changed to work with a different hardware configuration. The best way to check out a product is to buy the owner's or user's manual *before* you buy the product itself. You may also want to see if anyone in your local computer club can offer any advice. Buyer, be informed.

I have tried to keep this list as up-to-date as possible, but I suggest that you consult current catalogs for price, product availability, etc. I would like to hear about any products that I missed.

Some companies will sell blank boards with documentation. Some will break up a package and sell single boards.

SS-50 Bus Mainframe Manufacturers

Smoke Signal Broadcasting
6304 Yucca
Hollywood, CA 90028
(213) 462-5652
Mainframe with internal disk.

Gimix, Inc.
1337 West 37th Place
Chicago, IL 60609
(312) 927-5510

JF Products
1441-5 Pomona Rd.
Corona, CA 91720
(714) 734-6900

Southwest Technical Products
Corporation
219 West Rhapsody
San Antonio, TX 78216
(512) 344-0241

Febe Group, Inc.
51 Hamilton Ave.
York, PA 17404
(717) 854-0481

ECB SS-50 mainframe with keyboard,
case, power supply and space for
disk drives.

Midwest Scientific Instruments
220 West Cedar
Olathe, KS 66061
(913) 764-3273

SS-50 Boards

Ercom Data Company, Inc.
211 North Kirby
Garland, TX 75042
(214) 272-3421
Processor cards, disk drives, software.

Digital Research Computers
(of Texas)
POB 401565
Garland, TX 75040
(214) 271-3538
16K-byte static memory card.

Compuware Corporation
POB 2710
Cherry Hill, NJ 08003
(609) 428-2309
I/O calendar/clock with software.

Roberts Control Equipment
3640 Weston Rd., Unit 3 Weston

Ontario, Canada M9L 1W2
(716) 631-8178 (USA)
(416) 749-5062 (Canada)
64K-byte dynamic memory card.

Quality Research Company
POB 7207
Spokane, WA 99207
Two acia (serial) on one I/O card.

Digital Service and Design
POB 741
Newark, OH 43055
Bare boards only (i.e., no parts, just
parts list and schematics), with data
and edge connectors, 6847 Color
Graphics card.

Star-Kits
POB 209
Mt. Kisco, NY 10549
(914) 241-1027
Humbug Monitor — single board
computer.

Southwest Microsystems
6803 Kings Point Lane
Austin, TX 78723
(512) 473-6983
64K/256K-byte dynamic memory
board.

Hazelwood Computer Systems
7413 North Lindbergh
Hazelwood, MO 63042
(314) 837-3466
I/O slot 256 by 256 graphics card for
standard monitor (not vector
graphics); also a dealer.

JPC Products
POB 5615
Albuquerque, NM 87185
(505) 294-4623
16 channel analog-to-digital converter
board, 8-bit data, software con-
trolled gain, 3300 samples per sec-
ond, + / - 0.7 percent accuracy,
I/O slot 4800 bps cassette interface
with software.

Innovative Technology
510 Oxford Park
Garland, TX 75043
(214) 270-8393
8 channel analog-to-digital converter
board I/O slot.

Transition Enterprises, Inc.
Star Route Box 241
Buckeye, AR 85326
No phone.
SS-50 two piece extender board for

both I/O and main slot; control in-
terface board, DIP switch address
setting, opto-isolators on input,
reed relays on output, 8 channels.

Personal Computing Company
3321 Towerwood Dr., Suite 101
Dallas, TX 75234
(214) 620-2776
Blank prototype boards for SS-50 bus,
both sizes; Kansas City 300 bps
cassette interface I/O board.

National Multiplex Corporation
Box 288, 3474 Rand Ave.
South Plainfield, NJ 07080
(201) 561-3600
Z-80 processor card for SS - bus
with monitor in read-only memory;
tape controller card, NRZ RS-232
tape recorder.

Shifting Sands Microcomputer
Products Corporation
Box 441
Fairborn, OH 45324
No phone.

F and D Associates
Box 183, 1270 Todd Rd.
New Plymouth, OH 45654
(614) 385-2023
Bare boards only; 6502 processor card
for SS-50 bus; PROM programmer.

Thomas Instrumentation
168-8th St.
Avalon, NJ 08202
(609) 967-4280
Backplanes with no address decoding.

Micro Works
POB 1110
Del Mar, CA 92014
(714) 756-2687
TV camera interface; blank boards;
PROM (2708) boards.

Noble Computer Corporation
POB 7035
Portsmouth, VA 23701
(804) 465-1814
S100 to SS-50/SS-50 to S100 card,
software included.

SS-50 Dealers

Star-Kits
POB 209
Mt. Kisco, NY 10549
(914) 241-1027
6802.

Thomas Instrumentation
168 Eighth St.
Avalon, NJ 08202
(609) 967-4280
Dealer; 6800; SS-50 single card.

Kenyon Microsystems
3350 Walnut Bend
Houston, TX 77042
(713) 978-6933
FORTH for 6800, 6809.

Computerware
1512 Encinitas Blvd., Box 668
Encinitas, CA 92024
(714) 436-3512
Dealer; business software.

AAA Chicago Computer Center
120 Chestnut Lane
Wheeling, IL 60090
(312) 459-0450
Dealer; software.

Personal Computer Place
1840 West Southern
Mesa, AZ 85202
(602) 833-8949
Dealer.

Computer Systems Center
13461 Olive Blvd.
Chesterfield, MO 63017
(314) 576-5020
Dealer; also software.

Innovative Technology
510 Oxford Park
Garland, TX 75043
(214) 270-8393

Computers Plus
5970 Broadway Blvd.
Garland, TX 75043
(214) 840-1383

Hazelwood Computer Systems
7413 North Lindbergh
Hazelwood, MO 63042
(314) 837-3466

Dealer; also I/O slot 256 by 256
graphics card for standard monitor
(not vector graphics).

Single Board Computers

Star-Kits
POB 209
Mt. Kisco, NY 10549
(914) 241-1027
6802, not SS-50 bus.

Thomas Instrumentation
168 Eighth St.
Avalon, NJ 08202
(609) 967-4280
Dealer; 6800.

Software for the 6800/68XX(X)

Tallgrass Technologies Corporation
7623 West 86
Overland Park, KS 66212
(913) 381-5588
UCSD Pascal, disk system that can
back up 6 M byte; Winchester hard
disk drive.

LSI Enterprises Ltd.
POB 1227
Woodhaven, NY 11421
(212) 631-9242
Run 6800 code on 6809.

Micropi
2445 North Nugent
Lummi Island, WA 98262
(206) 734-8248
Screen editor for the CT-82.

Westchester Applied Business Systems
POB 187
Briarcliff Manor, NY 10510
(914) 941-3552
Business software for the 6809.

Kenyon Microsystems
3350 Walnut Bend
Houston, TX 77042
(713) 978-6933
FORTH for the 6800/6809.

Universal Data Research, Inc.
2457 Wehrle Dr.
Buffalo, NY 14221
(716) 631-3011
Database manager.

HHH Enterprises
Box 493
Laurel, MD 20810
(301) 953-1155
Software; dealer.

Computer Systems Consultants, Inc.
1454 Latta Lane
Conyers, GA 30207
(404) 483-1717/4570
Software; dealer.

Sonex Systems
Box 238
Williamsville, NY 14221
(716) 634-2466
Word processor.

F & D Associates
1210 Todd Rd.
New Plymouth, OH 45654
(614) 592-5721
Software; dealer.

Technical Systems Consultants, Inc.
Box 2570
West Lafayette, IN 47906
(317) 463-2502
Technical calls between 10 and 12
EST, Monday through Friday; all
kinds of software for the 68xx(x).

Microwave Systems Corporation
5835 Grand Ave.
Des Moines, IA 50304
(515) 279-8844
6800/6809 software.

Frank Hogg Laboratory, Inc.
130 Midtown Plaza
Syracuse, NY 13210
(315) 474-7856
Software.

Talbot Microsystems
5030 Kensington Way
Riverside, CA 92507
(714) 781-0464
68xx software; FORTH.

Washington Computer Services
3028 Silvern Lane
Bellingham, WA 98225
(206) 734-8248
6809 database management system.

Lucidata
POB 128
Cambridge
CB2 5EZ, England
Pascal for the 6800/6809.

Blue Hat Software
Box 4127
Flint, MI 48504
(313) 738-2863 evenings
Percom disk software.

Great Plains Computer Company
POB 916
Idaho Falls, ID 83401
(208) 529-3210
Software package that can process ob-
ject code for 6800 family of proces-
sors and 6502.

Alford and Associates
Box 6743
Richmond, VA 23230
(804) 320-6722
Software — video memory I/O
drivers.

Cer-Comp
5566 Ricochet Ave.
Las Vegas, NV 89100
(702) 452-0632
Software for 6800/6809, Pascal,
FORTH.

A-Vidd Electronics Company
2210 Bellflower Blvd.
Long Beach, CA 90815
(213) 598-0444
FORTH language, Strubal compiler in-
cludes editor and linking loader;
Software Dynamics BASIC com-
piler and other software.

Hemenway Associates
101 Tremont St.
Boston, MA 02180
No phone.
Strubal, relocatable assemblers and
other software for the 6800/6809
and 68000.

Dynasoft Systems
POB 51
Windsor Junction,
North Saskatchewan
BON 2VD Canada
Pascal compiler for 6800.

Kenyon Microsystems
3350 Walnut Bend
Houston, TX 77042
(713) 978-6933
FORTH for 6800, 6809.

Computerware
1512 Encinitas Blvd., Box 668
Encinitas, CA 92024
(714) 436-3512
Dealer; business software.

AAA Chicago Computer Center
120 Chestnut Lane
Wheeling, IL 60090
(312) 459-0450
Dealer; software.

Other Items of Interest

SS-50 Computing
POB 398
Garland, UT 84312

(801) 257-5733
\$12 per year; modem phone (801)
753-6800 (300 bps).

6800/ICCD Journal
PO Drawer 2790
Norman, OK 73070
(405) 364-1119
\$18 per year.

'68' Micro Journal
3018 Hamill Rd., POB 849
Hixson, TN 37343
(615) 870-1993
\$18.50 per year.

FLEX Newsletter
TSC
Box 2570
West Lafayette, IN 47906
\$5 per year.

MAG-MEDIA-80
Computer Bulletin Board has informa-
tion on other computer bulletin
boards.
(415) 573-8768

For Information on Database Systems:

Directory of On-Line Databases
Cuadra Associates
1523 Sixth St., Suite 12
Santa Monica, CA 90401
4 issues/year for \$60.

Tom Quay
Lehigh Computer Works
1132-2 Tilghman
Allentown, PA 18102
(215) 437-0556
6809 bulletin board.

Praire Micro Clinic
Box 325
Herington, KS 67499
(913) 258-2179
Microcomputer repair services.

Technical Information Center
Motorola Semiconductor Products,
Inc.
POB 20924
Phoenix, AZ 85036

PROJECT ENGINEERS

Rensselaer Polytechnic Institute, located in the foothills of the Adirondacks in Upstate New York is conducting a search for project engineers to be employed in its industry sponsored Center for Manufacturing Productivity and Technology Transfer.

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Interested applicants should submit a personal resume and 3 professional references to: Thomas F. Molloy, Employment Manager, RPI, 110 8th Street, Troy, New York 12181.



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Book Review

The Role of Computers in Manufacturing Processes

by Gideon Halevi

Published by John Wiley & Sons, New York, 1980

Reviewed by J. F. Derry

Gideon Halevi has his credentials in order: Ph.D., Mechanical Engineering; currently Director of CAM/CAD Research and Development Center in Tel-Aviv; a former manager of Data Processing. It is in view of Halevi's wide ranging experience that the corresponding wide range of subject matter in *The Role of Computers in Manufacturing Processes* makes sense. Almost anyone who must deal with this subject in industry should spend time with this volume, whether his interest is shop side or computer side, and manufacturing engineers in particular would find the contents profitable.

The contents of the book have been divided into three parts:

- Part I - Aspects of Manufacturing Technology — a State of the Art Review;
- Part II - Generative Process Planning;
- Part III - Hal-technology.

Halevi uses each section to develop the topic of Part III, Hal-technology (Hal means "all-embracing"). The amount of subject development the author considers necessary is impressive; only the final one hundred pages are devoted to Hal-technology, as compared to nearly four hundred pages on subjects which lead up to it. The quantity of information that must be coordinated to explain Hal-technology is voluminous and Halevi could not be expected to treat any subject in depth except the main points.

These, as it turns out, pertain mainly to the concept of generative process planning, a computer-based method that involves matrix mathematics in solving for optimal economics of manufacturing in determining the best process plan.

Generative process planning as developed by Halevi furnishes two important tools:

1. The ability to generate a practical optimum process plan in seconds.
2. The ability of the computer to "see" a component, manipulate it, change it, store thousands of components drawings, and retrieve them by key . . . or by attributes . . .

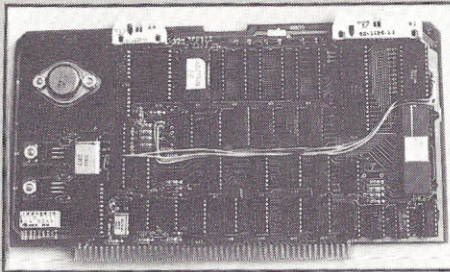
Halevi's viewpoint on product design and manufacture are also somewhat forward-looking: "Hal treats the manufacturing process as one interactive problem starting from engineering design to product shipment. It considers the manufacturing process as a nucleus and satellites rather than as a chain of activities. The engineering activities are the nucleus, and the other activities are the satellites. . ." This is not yet a prevalent viewpoint in manufacturing technology though the idea should be nurtured where possible.

There are plenty of flowcharts, equations, diagrams, and tables to illustrate the text. Anyone familiar with shop practice and shop mathematics should feel right at home with this book. And computer specialists should find a ready source of new ideas for dealing with shop problems.

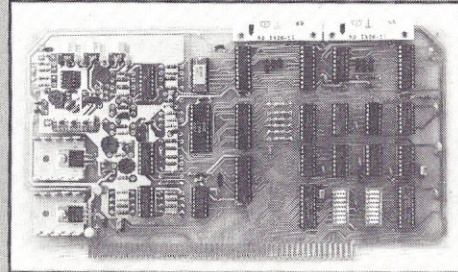
It should be noted, however, that 500 pages is not enough space to encompass the role of computers in manufacturing processes and therefore many important topics such as computer aided design (CAD), computer aided manufacturing (CAM) and numerical control (NC) receive only scant mention. Halevi has written something of a primer-in-depth for busy professionals who need to expand their horizons, and his book is certainly not an encyclopedia. It is however essential to a complete understanding of intelligent machine technology in one of its most important applications. ■

S-100 UPDATE SHEET #3

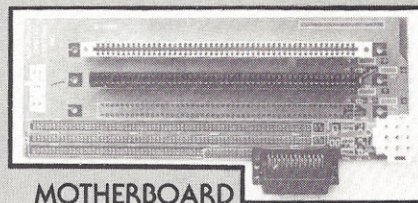
the equation:



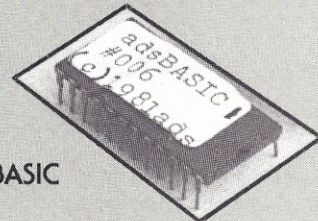
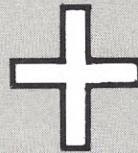
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Our Single Board Computer, utilizing the powerful MC6809 micro-processor, gives you exceptional computing power. Speech synthesis with the Votrax SC-01* I.C. for unlimited capabilities. Our powerful small Basic, (in 2716 eeprom), residing on-board in our MC6809 S.B.C. gets your system up and running at a low cost, but with plenty of power. All of the above combined into our 3 slot Mother Board means portable power!

*VOTRAX. TRADEMARK OF FEDERAL SCREW WORKS, INC.

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And a lot more, including a prom programmer S-100 card, (programs 14 different devices), sound effects, a prototyping card, all compatible with the I.E.E.E. 696/S-100 bus.

You need to know about us!

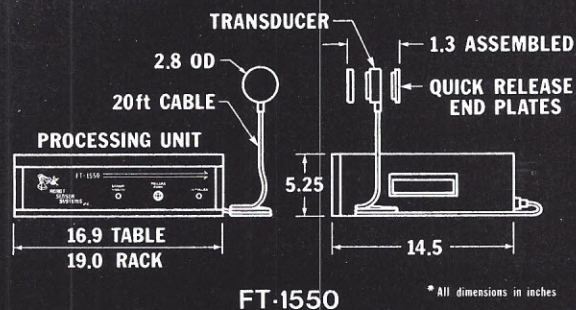
As the saying goes, we have solutions looking for a problem, well-engineered solutions. Call or write us today for a complete catalog.



Ackerman Digital Systems, Inc.
110 N. York Road; Suite 208
Elmhurst, Illinois 60126
(312)530-8992

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THE FIRST AFFORDABLE FORCE/TORQUE SENSOR

- Senses forces to 15 lbs. and torques to 50 in-lbs.
- Automatically resolves transducers readings into force and torque components in Cartesian coordinates.
- Forces and torques can be referenced to the sensor, the hand, or any tool coordinate frame defined in the robot's hand.
- Reference frame (sensor, hand, or tool) can be dynamically activated without interrupting the robot or task.
- High-speed microprocessor based transformations.
- Transmits resolved forces and torques at better than 100 Hz rates.
- Comes fully calibrated and ready to use.
- Continuously monitors its own health for dependability.
- Failure port automatically flags sensor failure or power loss.
- Quick calibration update procedure for real-time adjustments.
- Least squares recalibration procedure allows as many as 60 user selectable calibration loadings for accurate in-house sensor calibration.
- RS 232C serial port with user selectable baud rates to 38.4K baud.
- 16-bit TTL parallel interface with handshake.
- Overload protected to five times load rating.
- Quick connect/disconnect end plates allow removal or attachment of hand or sensor in less than 60 seconds.
- Rugged enough for the most demanding industrial environment (environmentally sealed transducers optional).



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\$2250

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213/444-4689

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Product

Company

- | | |
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| 25 | University of Florida, p. 51 |

Jan/Feb 1982

WORKING WITHIN LIMITS

by Robert A. Peck

Datapath

P.O. Box 2231

Sunnyvale, California 94087

This article describes the design constraints and techniques used to employ a 6502-based single board computer as a six motor robot arm controller. The arm itself is a MiniMover-5 made by Microbot, Inc. The single board computer is the Synertek Systems SYM-1 shown in Photo 1.

Low cost, a large number of input/output lines, and ease of memory expansion without going beyond the confines of the board were major reasons for choosing the SYM-1. Based on this one board capability, we decided to use only the built-in keypad and six-digit, seven-segment display for all interactions with the human operator while providing the maximum number of programmable features for controlling the MiniMover-5.

Designing a Control Language

The first design step is defining the available arm functions we need to control. These include:

- A. Disconnect power from all six motors to allow manual arm positioning.
- B. Reconnect power to all six motors.
- C. Step any one of the six motors forward or backward.
- D. Sense when the hand's grip switch is closed.

ARMBASIC, an extension to TRS-80 or Apple II BASIC (included with each MiniMover-5), provides an easy way to control the arm from within a BASIC program. For the sake of obtaining maximum capabilities for minimum costs, we decided not to add BASIC to the single board computer, nor to write the controlling program in BASIC since it would take up too much memory space. Therefore, assembly language was used exclusively.

Robert A. Peck is an independent consultant working in the areas of robotics, computer hardware, and software applications. He has a Bachelor of Science Degree in Electrical Engineering from Marquette University and a Masters of Business Administration from Northwestern University. He has been involved in electronic design and applications for the past 12 years.

With these functions directly available for arm control, what user-interface functions would be useful? Some useful commands are:

- A. Turn off motors to allow manual placement.
- B. Manually step the motors in either direction.
- C. Allow full interactive arm movement programming.
- D. Save, load, and edit stored control programs.

The principle of interactive program development is particularly important for our single board computer because no specific language is being developed which allows us to "work a problem on paper" in advance of the actual program effort. We felt that programs would be more easily developed interactively. The robot arm could then be instructed to:

Do this . . .
Do that . . .
Wait a while.
Check something out . . .
Go back and do part of that again.

This could all be done without becoming bogged down in technical details.

Different Levels of Control

Various levels of control are required in a system of this complexity. A learning mode is provided which allows manual positioning of the six motors. Pressing a control key establishes "this is the ending point for this step" and then goes on to the next step. Varying time delays can be added between steps to fine tune how quickly the arm responds to its environment.

To save program space, a way has been provided to repeat previous steps in the program based on either a specific count of steps or some external event. The control program itself has been written in a modular fashion that allows extra features to be added with minimal impact on previously programmed functions.

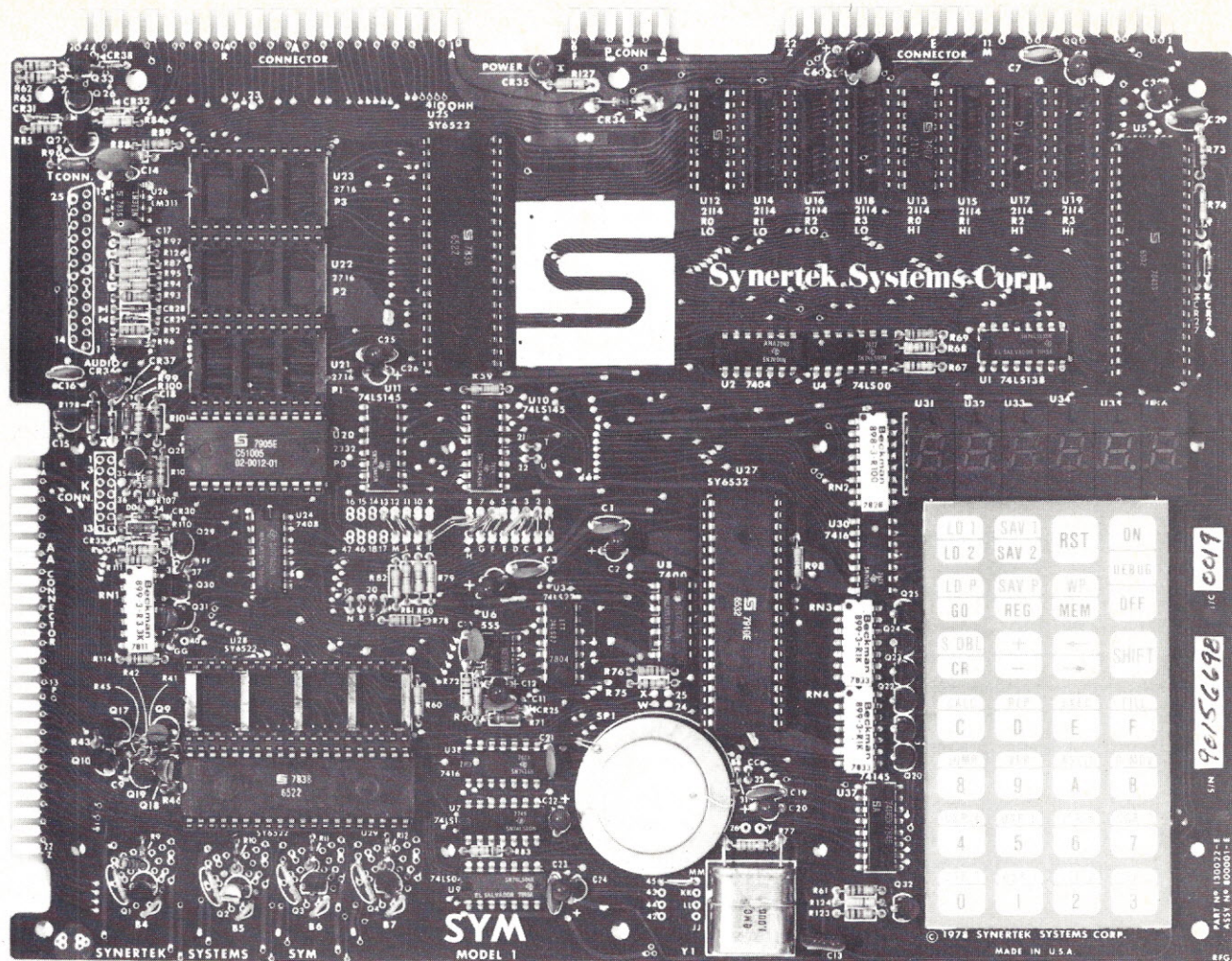


Photo 1: The Synertek Systems Corporation SYM-1 6502-based single board computer.

Using a Limited Capability Display

Because programming is designed to be interactive, the visual feedback from the arm's motion reduces the need for information to be presented through the seven-segment display. Only the data corresponding to the operating modes is required. The words representing these modes can, for the most part, be carefully selected to be readable on the limited seven-segment display used in this implementation. Figure 1 shows the seven-segment alphabet we are using along with some of the control words.

Follow the Bouncing Key

The computer can respond so quickly to keyboard input that if a key has not completely settled (as is the case with most point-contact entry keyboards) one keypress will often appear as multiple entries. This can be maddening when only one entry is desired.

One way to "debounce" a key is to sense when the key is pressed, store its value, wait in a do-nothing loop for a time,

and see if the key is still closed. We can stay in this loop until the key is released, then use the stored value to determine which key was pressed and execute the desired operation, thus guaranteeing that a single keypress (with possible bounces) will not be interpreted as other than a single keystroke since the initial time delay used allows the key to settle.

This technique is required for a command key which must represent only one keystroke with a meaning such as "this is the end of this step, go on to the next step." If bounces are not deleted, intermediate programming steps might be skipped, the program can become quite erratic, and memory will be wasted as well. Numeric data entry also needs to be debounced to assure that single digits are entered on each keystroke. The debounce technique is not appropriate when in the manual motor move mode (during interactive programming) since moving a motor 100 steps would require 100 keystrokes. The keyboard scan module is written to allow optional key debouncing. Turning off the debounce option allows a key to be held down to enter multiple steps.

Program Design

A set of six counters is used to keep track of the current stepper motor positions. The control program that our computer follows consists of a series of definition bytes (a byte is a set of eight computer bits, each represented by a one or zero). A definition byte specifies the type of operation being performed, and can be followed by the control bytes which are part of the operation itself.

For example, if the operation is a Step, the computer must move as many as six motors in a smooth coordinated motion from the ending count of the preceding Step command to the ending count of the current Step. If the operation is a Delay, the computer must wait in a time measurement loop and then go on to the following step. A loopback operation causes the computer to test for a specified condition and branch back if the condition is true.

The control program we have developed allows a maximum of 99 steps to be programmed for a single sequence. To maximize the capabilities of such a program, each step consists of six simultaneous motor movements in a coordinated fashion, followed by a decrement and test of one of nine counters, followed by a test of a combination of external conditions which may cause a branch back to a previous step for repeated activity, followed by a delay of up to 99.9 seconds.

An example program sequence might be as follows:

1. Move all six motors from a starting position to a point where an object is located.
2. Position the hand so that the gripper can grab the object.
3. Close the hand one step.
4. Test the hand switch to see if the hand has closed enough to turn on that switch. Loopback to step 3 if it has not.
5. Step the gripper motor 10 more times to increase the grip pressure after hand switch is turned on to a value sufficient to hold the object during a lift.

Separating Functions Within a Step

Step 4 in the previous example used the loopback function based on external conditions. However, as previously stated, each step consists of a six-motor move (although one or more of the motions can be zero), the test/branch on external condition, the decrement/text counter for possible branch and delay function. Step 4 does not want to pay attention to any counter values; the external function alone determines if the loopback is taken.

In a situation where either an "infinite loop," or a branch on external condition rather than using one of the nine counters is desired, we do not want the loopback condition to take place if the counter contents decrement to zero. A way must be found to remove the counter decrement/test from the loopback decision.

The control program is designed to use counter numbers

1 through 9 in the loopback test mode. However, the controller accepts a default condition counter number of zero. If counter zero is specified, no decrement or test takes place and only the loopback on external condition mode is tested.

Program Editing

As previously specified, the control program area contains a definition byte specifying the operation to be performed followed by the control bytes for that operation. This approach allows efficient data storage since a step consisting of only a delay, or a test/branch, needs no additional memory storage to define a zero motion of the motors. However, using this type of structure complicates program editing since adding or deleting functions within a step requires moving blocks of memory around to open or close spaces within the memory area. We made an arbitrary decision to simplify the editor and speed up program development by reserving memory space for any unused parts of a step. Therefore, if a program requires a delay between steps 10 and 11, it is only necessary to display step 10's delay portion, change the value shown there, and the program is ready to run again.

Relative and Absolute Stepper Values

A 16-bit counter which gives the current step location of the motor relative to the original home position is maintained for each stepper motor. Information describing stepper motor

SEVEN-SEGMENT ALPHABET

A b C d E F G H I J K L M N O
P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0

EXAMPLE WORDS

rEAdY (MODE DISPLAY)
StEP07 (PROGRAM STEP)
Ed It (MODE DISPLAY)
HoNE (ACTIVITY INDICATOR)
b-rEA- (TEMPORARY HALT)
Ct4= (FOR COUNTER PRESET)

Figure 1: Limiting display output to the six 7-segment on-board displays allows the set of numbers and letters shown here to represent the various operating modes. The least distinct of these are: K, M, R, W, X, and Z. However, even these letters, in correct context, require little effort to recognize. The accompanying examples show how some of the words used by the program actually look.

motion can be stored in one of two ways, relatively or absolutely. The absolute positioning technique stores the actual position values the motors should be moved to within the program. Relative positioning stores the number of steps to add or subtract from the current arm position within the program.

We chose to use relative counter content to allow for loopback programming as shown in step 4 of the above example. Relative positioning also allows logically consistent default conditions to be defined. Defaults can be defined as all zeros for each relative motor counter so that no motor motion is made unless a value is defined during editing. If a motor is not to be moved, it seems consistent to have a zero count in an activity programming location. The defaults for other parts of a step are:

Loopback on nonzero count in counter zero (which never decrements and always contains zero). This causes a no-operation.

Loopback on true condition in none of the 16 possible conditions or combinations thereof.

Delay a total time of 0.0 seconds before the next step is executed.

External Condition Testing

As previously mentioned, external conditions can affect loopback to a previous step. This means that if the voltage on any one of 16 pins on a specific connector on the single board computer is between 3.2 and 5 V, the condition sensed will be a logic 1 or "true." If the voltage on that same pin is between 0 and 0.4 V, the condition sensed will be a logic zero or "false." Intermediate voltages show an undefined situation which could be possibly a one or a zero. (In other words, the connections are TTL compatible.)

The program performs a 16-bit logical AND with the 16 inputs and a previously defined "mask" to determine whether a specific condition has occurred. The mask is entered during the programming process and is determined as follows:

Suppose the robot arm must stay within the confines of a small sphere. Although the arm has a much longer reach, a switch has been added to sense both reach and swing. A step program has been written to move the arm out and to swing it to the left until either of the two limits are reached. If the limit switches are connected to computer inputs 1 and 3, then the condition to be sensed might be the continuous "on" or true state of both switches, so that loopback does not occur once either of them turns off. If the switches are connected in the following order:

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
then the "mask" is:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1

This means that switch numbers 2 and 4 through 16 are ignored in any loopback decision, and the only condition which will cause a loopback will be that both inputs 3 and 1 are true.

Assigning Keyboard Functions

The final decision to make regarding a single board computer as a controller is to assign the programming and control functions as logically as possible to avoid using either an external keyboard or stick-on overlays. We felt that the standard SYM-1 keypad was sufficient for our programming needs. The key functions have been listed below for various operating modes:

0 through 9: Ten numeric entry keys are used for entering step numbers or delay values, counter numbers and values, and AND mask entries. Keys 1 through 6 are used to select which of the six motors are being programmed in the learn mode.

A-F: Used for entering hexadecimal numbers in the AND mask and also as described below.

A: *Alter* operating mode, go from Learn to Ready, or *Advance* to next item within a programming step. For example, during programming there is a Step zero which defines the initial values for each of the counters 1 through 9. Key A will advance from counter 1, to 2, to 3, etc.

B: *Break* interrupts a running program but does not zero counters or return the arm to the home position.

SYM Connector and Pin Number	MiniMover-5 edge connector pin	Connection Name
A-8	12	OUT (Strobe)
A-7	40	A2
A-6	27	A1
A-5	25	A0
A-2	26	D3
A-3	32	D2
A-4	22	D1
A-14	30	D0
AA-1	8, 29, 37	GROUND
AA-6	20	D7-Jaw Switch
AA-H	24	D6
AA-7	28	D5
AA-J	18	D4
AA-8	None	External Conditions
AA-K	None	External Conditions
AA-9	None	External Conditions
AA-L	None	External Conditions
AA-10	None	External Conditions
AA-M	None	External Conditions
AA-11	None	External Conditions
AA-N	None	External Conditions
AA-12	None	External Conditions
AA-C	None	External Conditions
AA-3	None	External Conditions
AA-D	None	External Conditions

Figure 2: Connections between the SYM-1 single board computer and the MiniMover-5 robot arm. The last 12 pins listed are reserved for TTL compatible external conditions to be sensed by the program during loopback condition testing. The MiniMover-5 must be set up to accept 8-bit parallel information as defined in the User Reference and Applications Manual, pages 105 and 106.

C: *Count* displays the counter number used on this step for loopback condition.

D: *Delay* portion of step being edited is displayed and a specific value can be entered.

E: *Edit* mode is entered from Ready mode, or *Exit* the step being edited.

F: *Flag* test allows entry (learn mode) or modification (edit mode) of the conditions being tested for the use of the loopback to previous steps.

Go: *Go* starts the program stored from the preceding load command or the program which has just been entered.

Reg: *Register* the robot arm in the home position. In Ready mode this locks the arm in place after the o-key command which allows the arm to be manually positioned and zeros the internal motor position counters. During Learn mode, "Reg" causes the arm to return to home position. After a break (B-key) in Run mode, "Reg" returns the arm to home and is the means of permanently stopping a running program since the break is only a temporary halt.

+ / - : Move the motor being programmed during learn mode in a "right" direction (right is an arbitrary designation that could represent up or down, clockwise or counter-clockwise).

← / → : Move the motor being programmed during Learn mode in a "left" direction.

S2: *Save* a program on cassette.

L2: *Load* a program from cassette.

These carefully defined keys together with the program structure provide the programmer with a high degree of control. Because of the way the program and data are structured, certain functions, if unneeded (such as delay or loopback) can simply be ignored during the programming process. Note that the above key description does not represent the full functional characteristics of the controller; we hope, however, it does give a flavor for the capabilities.

Expanding Functions

Extra functions can be added to the control program if desired. Possible functions include: coordinating multiple robot arms using a single controller; loopback or branch forward based on logical AND, OR, or Exclusive-OR operations with the 16 available external conditions; expanding memory to allow more than 99 steps in a single sequence; connecting an external computer via an RS-232C link; and so forth. Your comments and suggestions are always appreciated. ■

ROBOTICS AGE

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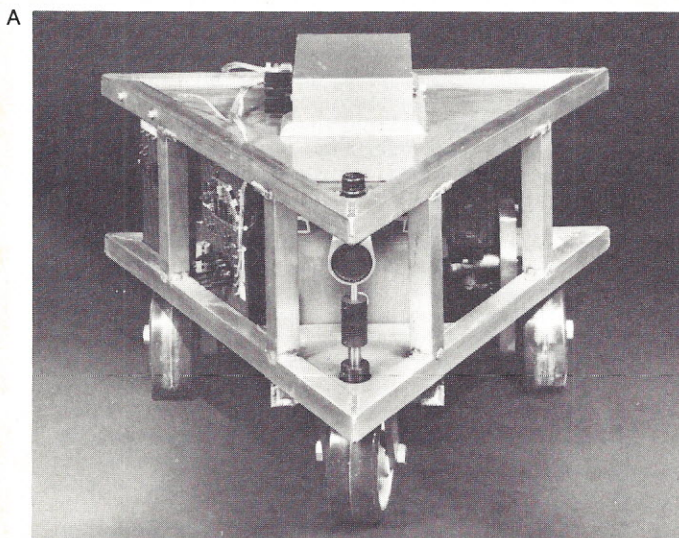
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AMBULATRON: ANOTHER CONTEST WINNER

by Glenn Hoffstatter

12655 Beatrice Street

Los Angeles, California 90066



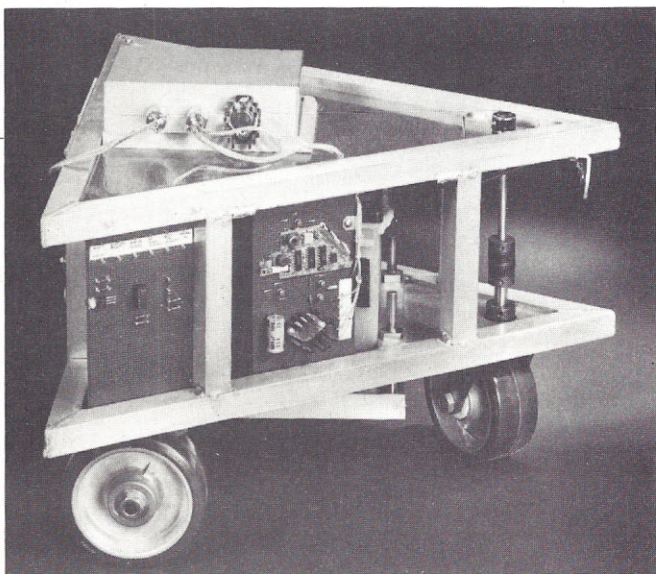
When I first began surveying all of the existing robot designs and configurations I was amazed by the great disparity between the popular notions of what robots should be and the pitiful immobile creations that they are today. To my mind, a robot is not just an arm, no matter how tirelessly it welds, nor is it a box that listens and talks. And while amoeba-like machines that wander aimlessly might serve to fire the imagination they still aren't robots.

If robots are ever to truly deserve their name, two things must happen. The first of these is structural simplification; robots must divest themselves of the encrusting electromechanical complexity that ancient technologies have foisted upon them. And second they must become auto navigating beasts. That is, animate machines that know where they are and how to get to whatever destination they or their masters choose. These were the guiding ideas behind the design of this, my first robot. I call him Ambulatron, and this is the story of his growth and evolution.

Achieving the first of my stated goals was easy; in fact, the structural simplicity I sought was a natural consequence of appropriately applied microprocessor technology. One of the nice things about microcomputers is that it is often possible to trade expensive and troublesome electronic and mechanical hardware for software complexity. In designing Ambulatron I've tried to take maximum advantage of this principle, reducing the overall construction efforts and cost while hopefully enhancing the aesthetic appeal of the device.

Expanding this theme, it has always seemed to me that it should be possible to write appropriate algorithms such that

Photo 1. Three views of the Ambulatron robot platform. The front view (a) shows the steering caster's position sensing potentiometer at the top, as well as one of the two drive motor assemblies at the rear of the device on the righthand side. In the second photo (b) we see a side view of the device and two of its electronics boards. The rear view (c) shows details of the power transistors. The structure of the device hides all but the lower tips of the drive motor assemblies with drive wheels mounted. A battery occupies the central part of the structure in all three views, providing both mass for stability and the necessary power for a free roving platform.



B

two drive motors could provide for all modes and motions involved in ambulation. The behaviors I speak of, and planned for, include locomotion along very straight lines for precisely measured distances, the precise execution of turns through specified angles, and the ability to travel at various speeds.

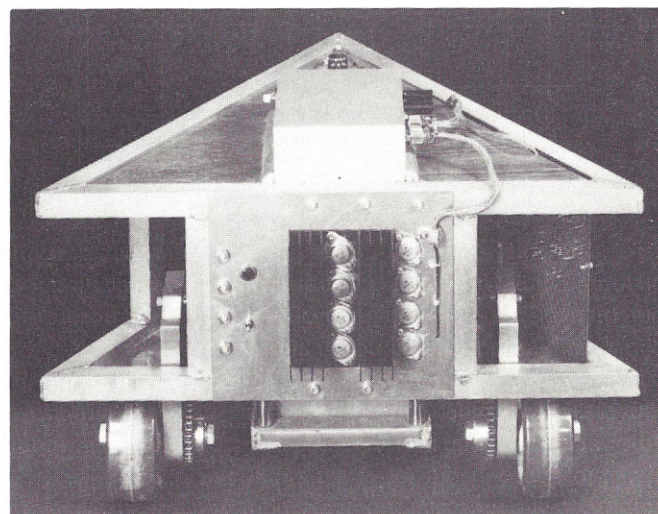
With these goals in mind I began devising motor drive and speed feedback circuitry in conjunction with controlling algorithms. The drive circuits are simple electronic switches, capable only of turning the motors on or off. Their only special feature is that they provide for the switching of large current loads at relatively high rates.

As I intended, the greatest complexity is concentrated in the system software. Here, using information about motor speed differences flowing to the micro, corrections are made to the width of the driving pulses, which are being sent to the motors by the computer. The amplitude control of any parameter by varying the width or frequency of driving pulses is called pulse width modulation (PWM). The controlled parameter might be speed, intensity, pressure, etc.

The motors I chose for Ambulatron are Cadillac electric window units. While far from precise, their separate forward and reverse windings, mechanical suitability, and low cost make these motors an attractive choice. The spare parts of standard automobile engineering become the actuators of the modern robot.

The motors are not synchronized, however, and would propel the robot in circles were it not for the control algorithm. Part of the system's beauty is that even the cheapest motors can be made to run in synchronization if they are within fifty or sixty percent initially. (I'm uncertain of the actual limits; my motors speeds were fifty percent different when free running, yet the robot runs a perfectly straight line under algorithmic control.)

Because pulse width modulation requires fairly high switching rates and because my motors are pulling large current loads, I immediately discarded conventional relays when designing the motor drive circuitry. The fast switching of high current levels was achieved by arranging two large power transistors back to back in pseudo-Darlington configuration shown in Figure 1.



C

By providing an alternate current path, the power diode serves a dual purpose. It suppresses electromagnetic interference (EMI) with the computer and protects the driving transistors against the induced back E.M.F. caused by the coil's inductance.

Interfacing of the microcomputer and the drive transistors is achieved via a UCN 4401 latch driver. Utilizing this device requires only four data line inputs and a chip select. Adjacent to each data line input is a corresponding open-collector output. Strobing the chip select while a data line is high results in the latching of the adjacent output. The chip has four outputs, each tied to a motor winding. Two are tied to forward windings and two to reverse windings. Activating any output and its associated winding simply requires writing the binary number corresponding to the channel(s) to be selected by the address of the 4401 latch.

As I stated, my algorithm provides for closed loop control over data outputs from the microprocessor in response to data feedback from the motors. The necessary motor speed data may be acquired in a number of ways. The most promising among these lie in two very different directions.

One approach requires the processing of analog voltage signals derived from a potentiometer. The potentiometer is linked to a swiveling front caster so that varying caster positions result in proportional voltage changes across the wiper. A National Semiconductor analog-to-digital converter, part number ADC0816, is responsible for digitizing the analog voltage signal from the potentiometer and providing it to the central processing unit of the computer. This approach works but suffers numerous drawbacks. Most of the problems are due to the essential incompatibility of analog signals with digital computers. The most significant problems arise in the areas of potentiometer precision and continuity, analog-to-digital converter resolution, reference voltage stability, and caster interaction with surface irregularities, resulting in the generation of inappropriate data.

By eliminating the caster-potentiometer link and substituting a gyrocompass, this last problem could have been avoided. And although gyros are expensive, difficult to find, and present a variety of challenging software problems, this

avenue has some real possibilities for robot navigation and shouldn't be discarded without a try. Surplus gyros from aerospace equipment, as well as new equipment, should be given attention by the experimenter.

A second, more attractive approach to the problem of motor speed data acquisition utilizes optical encoders. These devices use a rotating slotted disk to interrupt a light beam which is transmitted continuously from an infrared LED to

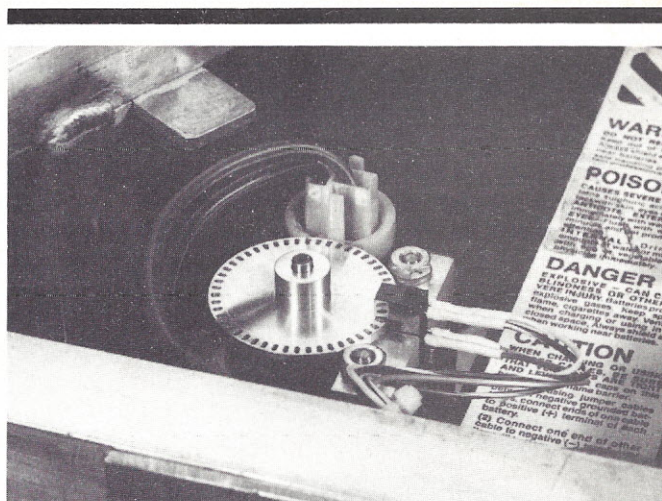
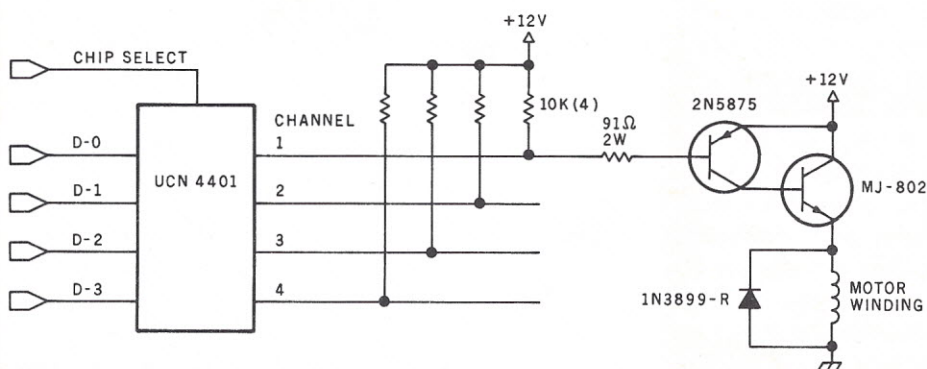


Photo 2. The optical encoder assembly for the motor speed control is shown in this view of the platform. The drive motor is viewed with the top plate of the structure removed, and two custom fabricated parts of Figure 2 can be seen. The encoder disk is mounted on the General Motors power window drive assembly's motor shaft. The custom-made bracket mounts the MCT-8 optical limit switch such that its beam is interrupted by the encoder disk. Every time a hole in the disk passes through the optical limit switch's beam, the output of the switch changes state and toggles a counter. This senses the passage of the hole in a way a computer can understand.

MOTOR DRIVE CIRCUITRY



HEX VALUE INPUT TO LATCH (D0-D3)	CHANNEL(S) SELECTED
1	1
2	2
3	1,2
4	3
5	3,1
6	3,2
7	3,2,1
8	4
9	4,1
A	4,2
B	4,2,1
C	4,3
D	4,3,1
E	4,3,2
F	4,3,2,1

Figure 1. The motor drive circuitry for Ambulatron's pulse width modulation scheme uses this hardware. Pulse width is measured by the program driving one of several single bit outputs. The state of these outputs is set by the code presented to the UCS-4401 decoder. Each output bit drives a pseudo-Darlington transistor configuration which controls the current through a motor coil. Note that the motor coil has a diode for electromagnetic interference and inductive transient suppression.

a photo-transistor, thus producing a digital signal, the frequency of which is proportional to the disk rotational speed. Because their output is digital, encoders are easily interfaced with microcomputer circuitry. In addition, they present a light programming burden making them ideal for robotic applications.

The encoder disks could have been attached directly to the driven wheels. Driving them off the motor armatures, however, improves resolution by a factor of 46 due to the ratio built into the motors' output reduction drive.

Rather than invest in expensive off-the-shelf encoders, I built my own from commercially available components. The optical transmitter-receiver (part number MCT8) is a single component, optical limit switch, available from General Instruments or Monsanto. The interrupter disk of Figure 2 con-

tains 50 slots giving a count of 2300 pulses per revolution of the motor output shaft. The signal outputs from the optical limit switches require squaring and amplification before they can be counted by the micro. An LM339 comparator circuit shown in Figure 3 provides this squaring and feeds the amplified encoder signals to the clock inputs on two channels of an Intel 8353 programmable counter-timer. The mounting bracket shown will place the MCT-8 device at the right position to sense the holes in the disk.

Although it may seem too simple, this is truly all the hardware required to implement pulse width modulation control over a pair of driving motors.

Now let's take a look at the system integrating software — that is, the list of do whiles, if's, and or's, responsible for turning this maze of plastic and wire into an intelligent, purposeful machine. As we proceed we will see how an algorithm is capable of providing for travel over a wide speed continuum, how it is able to equalize the speeds of the two motors, and how, if so desired, it can neutralize motor speed differences while varying their overall rate. We will also see how simple software additions, in conjunction with the described hardware, can make very accurate turns possible.

Pulse width modulation is usually used to control two state (on/off) type devices to make them behave as if they had intermediate states, i.e., in an analog fashion. It may be implemented in one of two forms as shown in Figure 4. One arrangement uses driving pulses of a constant width, achieving speed control by varying the frequency of the delivered pulses. This technique is properly called pulse frequency modulation. True pulse width modulation uses a constant frequency achieving amplitude control by varying the duty cycle of the pulse. By "duty cycle" we mean the proportion of time spent in each binary state of the signal.

Ambulatron uses only this second pulse width modulation system but achieves considerable flexibility through the use of the micro and a few, somewhat complicated, software tricks.

The term "pulse width modulation" and the waveforms in Figure 4 suggest that pulse width modulation achieves control by turning the driven device completely on and off at some frequency and pulse width. If this were the case, the robot's resulting motion would be quite discontinuous and oscillatory. (Ambulatron long suffered this malady.) What we are really trying to do is achieve motor speed control via magnetic field density modulation. This is accomplished by cutting off supply current during each drive cycle, only long enough to allow partial magnetic field decay.

Because we must never allow the magnetic field of either motor to totally collapse, there is an upper limit to the amount of time a motor may be shut down during any cycle. The algorithm must respect this requirement. A software test easily provides this upper limit to the "off-time." In addition, there is a need for a lower limit to the motor "off-time" if the overall device velocity is to be varied.

If you're using different motors from those I use you will have to tune your software for their characteristics because

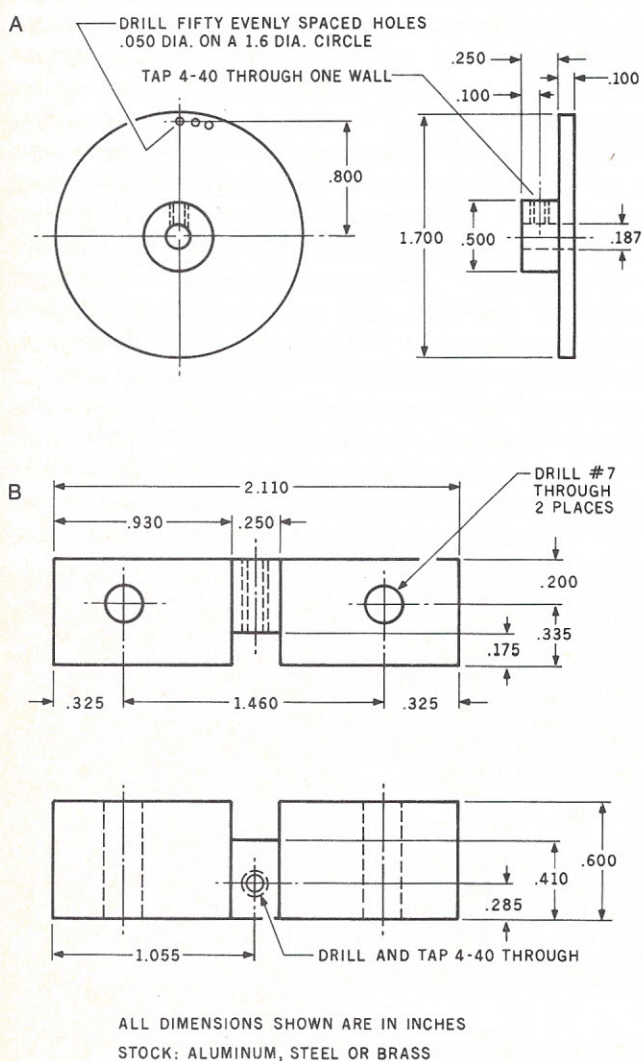


Figure 2. Two specially fabricated parts are required for adaptation of the General Motors power window motor assemblies. Each motor requires an optical encoder disk (a) and a mounting bracket (b) for the MCT-8 optical limit switch. Both parts are fabricated out of aluminum. The parts are shown assembled in Photo 2, as mounted on one of the Ambulatron drive motors.

magnetic field decay constants vary with armature and stator masses, increasing mass naturally equating to larger field decay constants.

Implementation of pulse width modulation control over the drive motors required the use of one channel of the 8253 hardware counter and the creation of three types of software counters. These counters, used to control the period of each program loop, are the foundation of my program. The number of program loops between corrections defines the actuation/deactuation proportion and the amount of time each motor is to remain off during each cycle.

Initially, both motors are set up to the same arbitrary duty cycle. Thereafter, adjustments are made to the registers controlling the duty cycle at regular intervals. The length of this interval, in milliseconds, is stored in a register. The body of my program, containing all executable code, is an endlessly repeating loop. The 8253 counter in mode zero provides timing control over the loop so that it executes exactly each millisecond.

Before entry into the body of the program, the counter register is initialized to sixteen. On each pass through the program (that is, once each millisecond) the counter register is decremented and compared to zero. When this counter times out, several things happen. First, the motors are shut off by writing zeros to the 4401 latch. The motor speeds are then compared and the faster motor distinguished from the slower. Next, to compensate for observed speed differences, the amount of time each motor should remain off during the current cycle is calculated and stored. Last, the counter register is reset to sixteen and program execution resumes. Working copies of the calculated time-off values are decremented by one on each pass through the program loop. The motors individually time out when the appropriate counter reaches zero. The corresponding motor is then turned back on by

adding the appropriate number to a storage register and writing this total to the 4401 latch.

In this process you'll note that motor speed differences are negated by shutting the motors off at the same time and turning them back on at different times. Speed balance is achieved by turning the inherently slower motor on sooner than the fast motor, and by doing all of this sixty or more times per second.

Of critical importance to this algorithm is the way the calculated off-time values are varied in response to detected motor speed differences. These values have upper and lower limits of 15 and 1 milliseconds, respectively. When Ambulatron is first fired up these registers are initialized to 7. When counter one times out, if the motors aren't synchronized, the encoder channels of the 8253 timer will contain different counts (with the lower count representing the faster motor). This is determined by latching the encoder channels of the 8253 into storage registers which are read as the timer continues counting. The speed correction factor is obtained by subtracting the smaller count from the larger and dividing this by three. If the speed differences are small, this value may be less than one; in this case, the correction factor is automatically set to one. Thus, all corrections are proportional to the motor speed differences. Large differences get large corrections, small differences (less than three encoder counts) are corrected by one. All initial corrections are made to the slower motor by subtracting the correction factor from the slower motor's stop-off register down to, but not below, its lower limit. This results in the speeding up of the slower motor during the subsequent 16 millisecond cycle. Each time the counter register drops to zero, this sequence is repeated until either the lower limit is reached or the motors achieve synchronization. If the lower limit is reached and the motor speeds remain imbalanced, speed corrections are then initiated on the

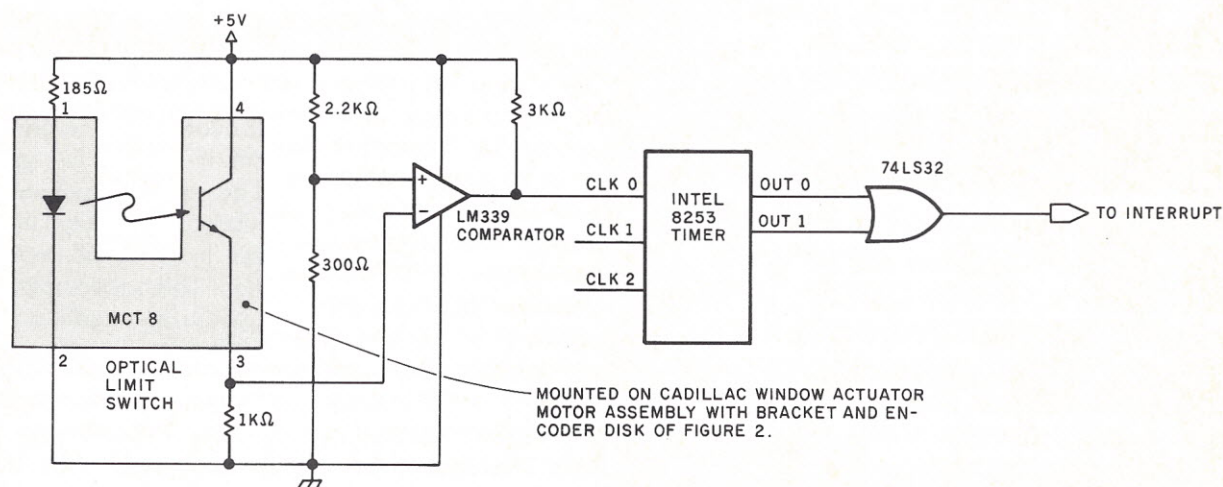


Figure 3. Optical encoder and signal processing circuitry. The optical encoder disk periodically breaks the light path between the LED and the phototransistor of the MCT-8 as the motor shaft turns. The digital logic of Ambulatron's computer control circuits requires a sharp crisp pulse — but the actual change in light output is long and slow. Thus, an LM339 comparator in this circuit is used to convert the slow light change into a square edge that toggles the 8253 counter circuit.

faster motor. Each time value is incremented by the correction factor until either the 15 millisecond upper limit is reached or motor synchronization is achieved.

If this entire process is implemented as I've described it, with the lower limit always being reset to the same fixed value, motor speed differences will be neutralized and the robot will travel at a fixed velocity in a very straight line.

Endowing the robot with the ability to vary its speed now becomes a simple task. Since the lower limit variables represent the least amount of time the motors can be shut off during each millisecond cycle, the overall speed can be reduced by raising the lower limit variables to values above one. While this reduces the speed of the lower motor, it does not interfere with the speed balancing algorithms. It's remarkable to see two very different motors working together in perfect harmony. When writing the code to implement this theory I found that the trick was to change the values in all of the registers by the same amount at the same time. Ambulatron reduces speed by incrementing all of these registers in proportion to either the distance to ultrasonically detected obstacles or the distance to the end of a programmed path.

Ambulatron possesses one last important feature, an outgrowth of its hardware, that I would like to briefly explore — the ability to make very precise turns in either direction.

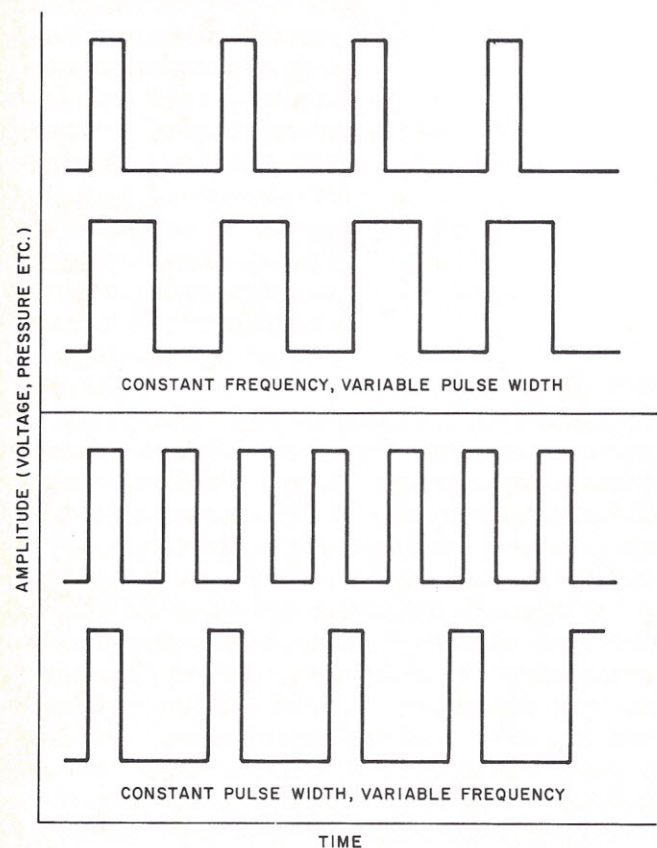


Figure 4. Two types of pulse width modulation. Modulation of pulse width or frequency can be envisioned. At (a) we show how a constant frequency signal can have pulse widths varied to convey information. At (b) we show how a constant pulse width can be frequency modulated by varying the period of time between pulses.

This is achieved using the 8253 discussed previously in reference to encoder signal processing. Each of the 8253's channels has an output pin that, in mode zero, goes high when the terminal count is reached. (Being a down counter, the 8253 always counts down to zero from whatever number is loaded.) The encoder channel output pins are tied through an "or" gate to one of the processor's interrupts (see Figure 3).

The easiest way to make turns using this setup is to drive one wheel and stop the other. Turning precision is achieved by programming the timer channel corresponding to the motor to be actuated. The timer is programmed in mode zero with the count corresponding to the number of degrees through which you desire the robot to turn. (Because the encoders are linked through the motors to the wheels there is a direct correspondence between the number of encoder output pulses and the distance traveled by the associated wheel.) When the encoders have been set up with the mode and count information the motor is then turned on via the 4401 latch and the robot begins to move. As it turns, the encoder generates pulses which the 8253 interprets as clock signals. The timer counts down once for each clock input, its output going high on the terminal count. This high output, through the "or" gate, generates an interrupt. The routine servicing this interrupt then stops the motors by writing all zeroes to the 4401. The robot stops turning, the main loop of the program is reentered, and the robot takes off once again in a straight line. (In case you actually try to implement this system you should know that the unused encoder channel of the 8253 must also be programmed to some large arbitrary value. This will prevent it from pulling its side of the "or" gate high before the turn is initiated.)

It has always seemed to me that, aside from improving their aesthetic appeal, auto navigation is the one great obstacle that must be overcome if robots are ever to outgrow their present "toy" status. I believe that the systems I have described are a quantum leap in that direction. Looking to the future, I plan to add a hexadecimal keypad interpreting software to the on-board computer thereby giving the operator a flexible means of communicating destination data directly to the robot. This data will be interpreted in the following manner. Since the route to any location in two-dimensional space can be broken down into a series of paths and turns, programming for travel between any two points in that space might be achieved using the turn-angle and distance travel information available from the encoders. If the robot knew its starting position and direction along with the desired destination, the necessary instructions to reach that goal could be stored in and retrieved from memory as directed by the operator or the robot.

All of this is, of course, experimental, and I don't really believe that open loop control will ever have the flexibility to handle all of the unknowns that arise in the real world. In the end, robots will probably need ultrasonic ears, television eyes, and certainly a great deal of work. But our goal is clear, with the path to that destination becoming clearer every day. Robots like Ambulatron are the great technological adventure of our time. ■

QUESTER

by
David L. Buckley
48 Agamemnon Road
West Hampstead, London, NW6
England

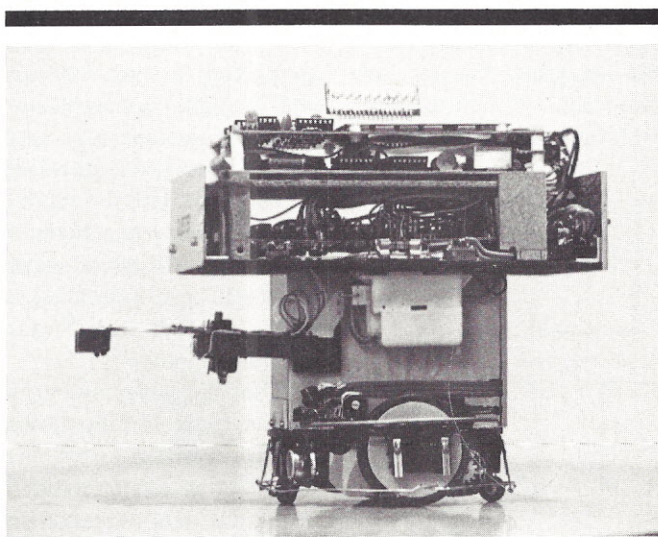
Quester is a table-top robot about 8 inches high, 8½ inches long and 5 inches wide, constructed mainly of 1/8 inch hardboard covered with Solarfilm, an iron-on covering for model aircraft.

The controlling computer is an Acorn System 1, 6502 based two-board microcomputer with 3½K bytes of programmable memory, 500 byte monitor, and 32 I/O ports. All programs are loaded from cassette tape.

Under the computer is an interface board containing bump reflex timers, hardware logic to interface the drive motors to the bump reflex timers, two 8-bit counters for distance measurement, and video digitizers for the vision system.

The chassis consists of two main drive wheels with fore and aft casters. The drive wheels are hardboard disks with vacuum-cleaner belts for tires, each powered by a 6V DC motor. Via homemade shaft encoders the motors also drive two 8-bit up/down counters so that a preprogrammed path may be followed. Wire loops connected to micro-switches can be seen around the base — these provide reflexes through hardware timers on the interface board. Power comes from a 6V lead-acid battery in the central column which allows about three hours of service between charges.

Twelve photo-transistors arranged as three pairs per side provide obstacle detection. One of each pair senses ambient light while the other is only sensitive to light from a particular direction. (Quester's normal world consists of a black baseboard with white obstacles/objects but since the robot is silver and black it doesn't photograph well against a black



background.) At the front of the chassis are a pair of ultrasonic transducers for range-finding.

Quester's arm has only 1 degree of freedom (up/down), relative to the body, plus a gripper, but this is sufficient to pick up blocks and move them about. The arm was built mainly from wood and paper clips.

The up/down motor is a model aircraft linear servo which moves the arm through a bell-crank arrangement. The gripper is operated

by a small electric motor with integral 16:1 gearing. The fingers are opened by an elastic band behind the motor and are closed by the motor winding up thread attached to lever-arms on the fingers. The fingertips have a parallelogram action as the fingers open and close and are faced with rubber under which are contacts closed by pressure to sense when an object is gripped.

Thus far, no complex programs have been written for Quester, as the project is just coming together. The robot is able to start, stop, go backwards/forwards, turn through various angles, approach an obstacle and stop at a given distance, lower and raise the arm, and operate the gripper.

Future plans are to rebuild the computer and interface to provide more ports and memory-map some of the devices. At present there is a great deal of contention between the hardware reflexes and the guidance programs, and I would like to put the reflexes in software. Also, three eyespots per side are not sufficient to cope effectively with even a blocks world. The arm is capable of many improvements and I am thinking about the Mk II version. ■

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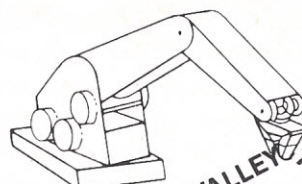


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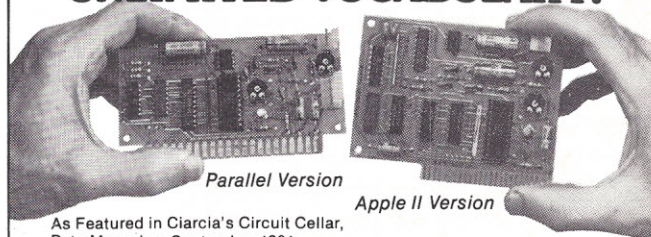
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SWEET-TALKER, IT GIVES YOUR COMPUTER AN UNLIMITED VOCABULARY.



As Featured in Garcia's Circuit Cellar,
Byte Magazine, September 1981.

The Sweet-Talker voice synthesizer allows you to add speech of unlimited vocabulary to your computer. Utilizing the Votrax SC-01A chip, you can output any message by programming individual phonemes. Comes in two versions; one plugs directly into your Apple II, the other connects to any computer with an 8-bit parallel printer port. + 12 volts and + 5 volts required for parallel board.

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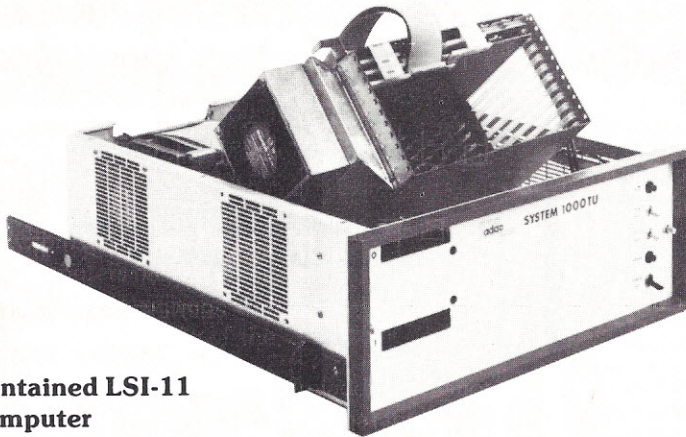
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New Products



A Self-Contained LSI-11 Based Computer

The ADAC System 1000TU LSI-11 bus enclosure occupies only 7 inches of rack space, yet accommodates up to 22 LSI-11 bus half-quad sized boards, 11 full-quad sized boards, or any mix thereof in its unique front facing tilt-up card cage. With its rugged, all metal construction and self-contained tape drives, the 1000TU is ideally suited as a dedicated program machine in both industrial and laboratory environ-

ments. The TU58 tape drives provide a total of 512K bytes mass storage.

The addition of a programming terminal allows the System 1000TU to be used as a stand alone development system utilizing ADAC's Prosys I operating system software and high-level process control language. Alternatively ADAC also supplies runtime RT-11 software with BASIC. Use of the System 1000TU in these applications is very practical because

software, once loaded from the tape, is totally memory resident. Thus, tape speed is of minimal significance to development time.

Additional features include full compatibility with all ADAC LSI-11 bus analog/digital interfacing boards, bus terminators and bus extender connectors standard on the back-plane, all metal construction with rack mount slides, orderly power up/down sequencing, and 50/60 Hz line clock. The System 1000TU is available in two basic versions, master and slave. A crystal controlled, strappable clock is optional.

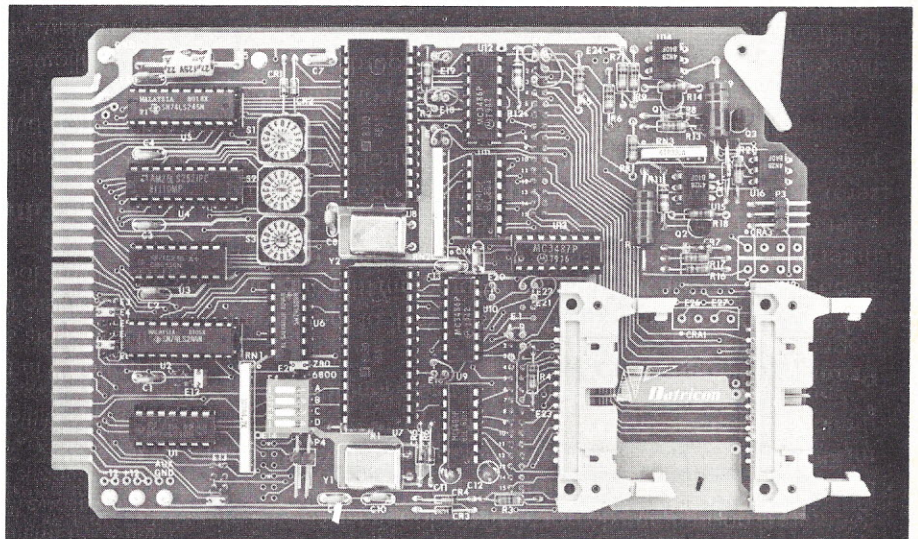
The System 1000TU master unit costs \$2995; System 1000TU slave unit \$2895; add \$100 for crystal clock. Delivery is 30 to 60 days after receipt of purchase order. For more information write ADAC Corporation, System 1000TU, 70 Tower Office Park, Woburn, MA 01801.

CIRCLE 36

Serial Communications Module for the STD Bus

Many dedicated industrial and commercial quality microprocessor systems are built using the so-called STD bus, an outgrowth of a bus specification originally defined by a company called Pro-Log. This serial communications module by Datricon Corporation is designed to provide two RS-232C or RS422 serial ports in STD bus computers based on the 6800 or Z-80 microprocessors.

A significant design point of the module is that all hardware options are under software control. Thus, data rate, word length, parity, and number of stop bits are controlled by the processor's software in addition to the usual request to send (RTS) and data terminal ready (DTR) lines. With software controlled data rates from 50 to 19,200 bps, it is possible to use



a software strategy to automatically hunt for proper data rate after connection.

Other miscellaneous features of these serial ports should be in every serious serial communication design.

The SER 02 module for the STD bus is priced at \$235 in hundred quantity. Allow four weeks delivery after receipt of order. Contact Datricon Corporation, 7911 NE 33rd Dr., Portland, OR 97211. CIRCLE 37

New Products

Turn a TRS-80 Model III Into a Z-80 Development System

By adding proprietary hardware and software to a mass-produced personal computer, it is possible to deliver a complete microcomputer development system at low cost. The Orion Instruments development system includes a Radio Shack Model III personal computer, EPROM/EEPROM programming hardware, Z-80 in-circuit emulation device, 48K memory and two double density disk drives installed by AM Electronics. Software includes editor, macro assembler, debugger/disassembler, interactive assembler, linker, relocater, spooler, and enhanced TRSDOS, as well as programs for programming and reading PROMs and in-circuit testing of RAM and ROM. Compatible cross assemblers are available for Z8, F8/3870, 8048, 1802, and several other micro-processors at \$150 each.

The EROM programmer comes with a personality module that can program 2716, 2516 (16K), 2758, 2508 (8K), 2532 (32K), EROMs as well as the new electrically erasable 2816 and 48016 (16K) ROMs. Other personality modules are available at \$15 each for 2732A and 2764 EROMs. The zero-insertion force socket of the programmer has 28 pins to allow for future larger ROMs.

The in-circuit emulator extends the TRS-80 bus into your target system via its Z-80 socket. Application pro-

grams can be run in the TRS-80 and the ports in the target system will respond. The application program can thus be tested by single stepping, setting breakpoints, etc., under control of the debugger in the TRS-80. An interactive edit/assembly/debug environment is provided to exercise and troubleshoot hardware in the target system.

The software allows interactive checkout of programs in small

in seconds. Program trace allows single stepping with display of all registers, a memory window, and mnemonics of the previous and next instruction to be executed. When the program works properly, it can be copied directly from volatile memory into an appropriate read only memory.

For customers who already have a TRS-80 Model I or III, the EROM programmer/Z-80 Emulator can be



modules which can later be linked together into a large system. The source code and interactive editor/assembler can be kept in memory during debugging so changes can be made and reassembled into memory

purchased separately for \$329. Delivery is quoted as 2 weeks after receipt of order. Contact Orion Instruments at 172 Otis Ave., Woodside, CA 94062.

CIRCLE 38

Shaft Encoding Application Note

A six page application note discussing the advantages of synchro to digital (S/D) converters and optical encoders is available from ILC Data Device Corporation. The company designs and manufactures data acquisition components, modules, and hybrids.

Entitled "Getting Reliable Digital

Data from Shaft Position Sensors," and authored by Stephen Muth, the application note describes various methods of converting analog output of position sensing devices to digital format.

Included are detailed discussions of synchro to digital converters, tracking and sampling types, and optical

encoders. Cost and performance comparisons between optical encoders and S/D converters are noted. Copies of the S/D converter application note are available from the Marketing Department, ILC Data Device Corporation, 105 Wilbur Place, Bohemia, NY 11716.

CIRCLE 39

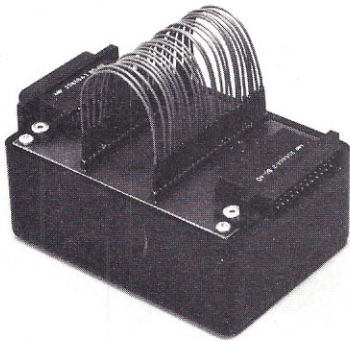
New Products

A Suite of RS-232C Accessories

As many readers already know, RS-232C is a nearly universal interconnection standard for serial communications. Terminals, plotters, digitizers, voice output devices, phone network accessories and other exotic intelligent sub-

systems can talk to one another using this method. But we often find problems mixing plug definitions and miscellaneous control signals. Here are three products that will help smooth over differences between RS-232C peripherals.

For Those Non-Standard RS-232C Interconnections . . .



The Model DA-120 RS-232C breakout box allows instant access to or exchange of all 25 leads in the in-

terface for instrumentation or diagnostic purposes. As such, the unit will prove useful in laboratory and development environments.

Its size is about 10 cm by 7 cm by 4 cm, and it is furnished with a storage case, spare field jumpers, and a list of EIA specification definitions of RS-232C signals.

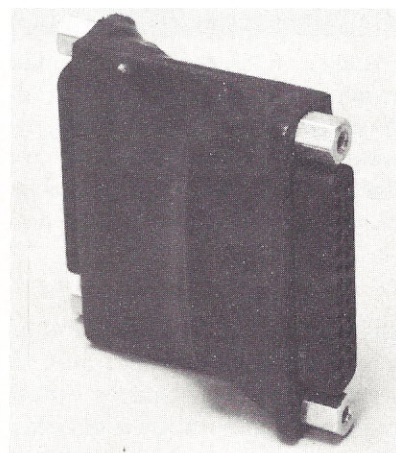
The Model DA-120 is priced at \$49, and delivery is quoted as two weeks. For further information, contact Development Associates, 1520 South Lyon St., Santa Ana, CA 92705. **CIRCLE 40**

Change Gender With This Accessory

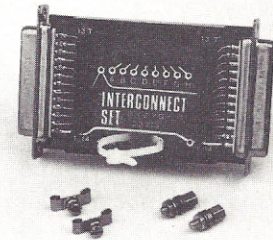
Have you ever been stuck with a male plug and a male socket for a new cabling interface? A quick fix is to use the Model DA-118 Gender Changer, a compact, low cost, and convenient method of connecting two RS-232C cables of the same gender.

Available in either male or female style, use of the Model DA-118 will often eliminate time and cost for field fabrication of special cables.

Price of the DA-118 is \$20 with appropriate dealer discounts available. Delivery is quoted as stock to two weeks after receipt of order. For ad-



ditional information, contact Development Associates, 1520 South Lyon St., Santa Ana, CA 92705. **CIRCLE 41**



A Flexible Male-Female Patch Set

The 232IS interconnect set is a flexible wire-wrap RS-232C patching device that consists of a printed circuit board having a standard RS-232C female connector on one end and a male connector on the other. All 25 RS-232C signals are passed to a header block near each end of the board. By use of either a permanent wire wrap or a temporary jumper, complete configuration of the interface can be quickly accomplished.

One feature of the set is the provision to "break-in" with a nonterminated RS-232C round cable directly to the board via a nylon tie and a row of holes in the PC board to which the individual conductors can be soldered. There are ten such holes for soldering and included are both protective ground and signal ground. The remaining eight holes are connected to a central 8-pin header block which permits field use of jumpers or wire wrap for configuration of either or both ends. The unit can be permanently attached to a cable by use of the locking hardware that is included.

Optional jumper sets of several multiple pin jumpers can be ordered at \$7.50 per set. This company also has a catalog with 30 different interfacing and cabling products for RS-232C interconnection. Contact Syzygy at 256 West San Bernardino Rd., Covina, CA 91723.

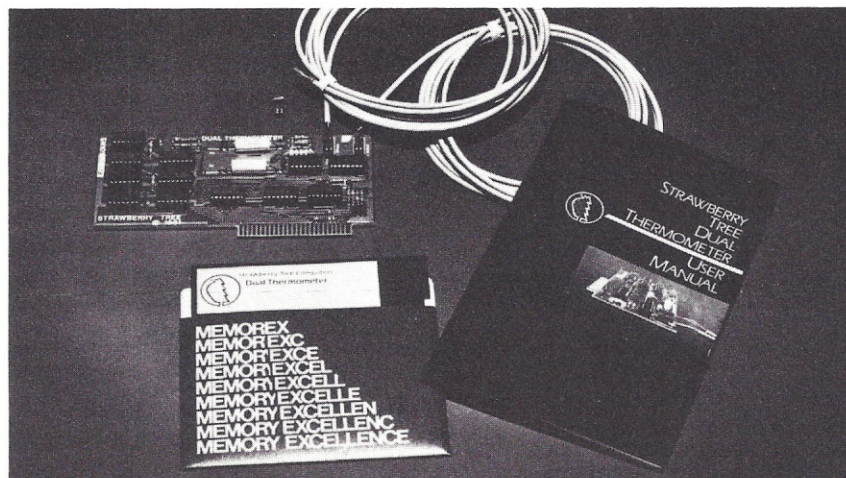
CIRCLE 42

New Products

Measure Temperature With an Apple and a Card

Here is an Apple II interface card that gives two separate temperature input channels. BASIC software supplied with the Dual Thermometer Card turns an Apple II into an analytical and measurement tool for home, industry, agriculture, and the laboratory. The software included with the product displays current temperature, maximum and minimum temperature during an interval, and the temperature difference between the two probes. If additional capability is required, several of these cards can be installed in empty slots of an Apple.

Each unit comes with two probes and ten feet of wire per probe. The temperature measurement range is



– 55 to + 125 degrees C. Accuracy is quoted as better than 0.4°C from – 20° to + 50°C, and better than 1.0°C outside that range. The probe cables can be extended up to 500 feet with no loss of accuracy.

The Dual Thermometer Card and

software requires a 48K Apple II with Applesoft BASIC and at least one disk drive (13 or 16 sector). This interface costs \$260, and is available from Strawberry Tree Computers, 949 Cascade Dr., Sunnyvale, CA 94087.

CIRCLE 43

GRADUATE RESEARCH PROFESSOR IN MANUFACTURING SCIENCE IN ROBOTICS UNIVERSITY OF FLORIDA COLLEGE OF ENGINEERING

The Mechanical Engineering Department, University of Florida, will establish a tenure-track graduate research professorship in Manufacturing Science to be associated with the Center for Intelligent Machines and Robotics. The graduate research professorship, is one of the most eminent academic positions in the university requiring exceptional attributes in research, teaching, and service. Individuals of the highest research stature are being sought. The individual must have proven academic and/or industrial experience documented by published results in the national and international literature. Experience in the disciplines of vibrations, automatic control, and experimental analysis are deemed essential. Evidence of strong interactions and support from recognized industrial and federal funding groups will be considered significant in assessing the potential contribution to the on-going program at the University of Florida. Expertise in applications such as metal cutting processes, numerical control machines, adaptive control in manufacturing processes, and the emerging field of robotics would represent desired technological attributes.

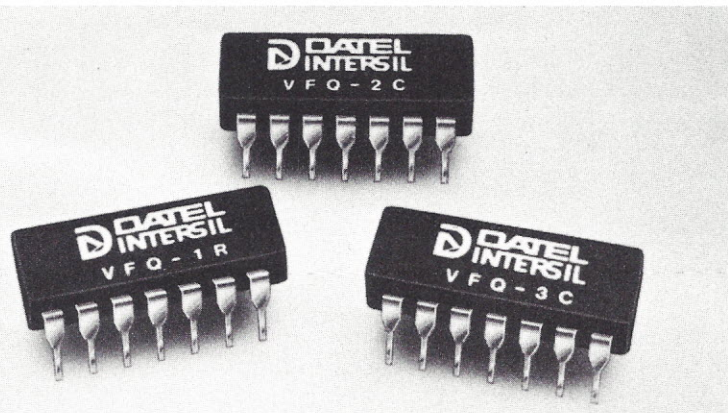
The individual will be asked to establish a major program in Manufacturing Science in cooperation with the departments of Industrial Engineering, Mechanical Engineering, Electrical Engineering, and Computer Science. The goal of such an effort is to make a significant advance in the science through major funding from industrial and governmental sources. In this capacity, the graduate professor is expected to make a significant advance in the science through major funding from industrial and governmental sources. In this capacity, the graduate research professor is expected to manage the research, work with graduate students, offer additional academic courses, establish workshops and educational programs for industry, and fully document in reports and in the open literature, the results of the program.

Salary will be commensurate with level of accomplishments and experience. Please address applications and nominations by the April 15, 1982 deadline to:

Dr. Donald J. Elzinga, Chairman
Graduate Research Professor, Search Committee
Department of Industrial Systems Engineering
University of Florida
223 Grinter Hall
Gainesville, Florida 32611
Phone: (904) 392-1464

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New Products



Low-Cost Voltage to Frequency Converters

One approach to the problem of sensing the real world of analog voltages is provided by voltage to frequency conversion. A digital signal's frequency is easily measured with a hardware or software time base and counter. Multiple digital channels can be selected with logic circuits at no cost in distortion of the frequency encoded information. But in order to use this technique in our systems we need to convert analog information (voltage) into frequency encoded information. Here are two cost-effective converters that will be of interest to our readers.

Datel-Intersil's VFQ2 and VFQ3 are new additions to their family of low-cost monolithic voltage to frequency converters. These devices utilize both CMOS and bipolar integrated circuit technology in a high performance charge balanced integrator circuit. The full scale output pulse rate can be set from 10 kHz to 100 kHz by means of two external capacitors. Both pulse and square wave outputs are available.

Linearities are specified for 10 kHz and 100 kHz full scale outputs. The maximum linearity, at 10 kHz of the VFQ-2 is 0.01%, and the VFQ-3 has a maximum of 0.25%. For a full scale output of 100 kHz, the maximum linearity of the VFQ-2 is

0.08%, and the maximum for the VFQ-3 is 0.5%. Linearity holds all the way down to zero output frequency. Normal operation requires three external resistors, two external capacitors, and a reference; if zeroing adjustment is used, a trimming potentiometer and two additional resistors are required. The devices can be operated as either V/F or F/V converters by external pin connection.

The internal circuitry of these converters includes an operational integrator, a comparator, digital delay circuit, single-pole double throw electronic switch, a start circuit, a divide by two circuit, and two output driver circuits. The two outputs are open collector NPN which sink up to 10 mA and give a logic HI up to +18 V. Each device is packaged in a 14-pin plastic DIP and operates over the 0°C to +70°C temperature range.

Common applications for these devices are remote transmission of data, temperature sensing and control, transducer encoding, flow measurement and control, long term integration, and voltage controlled oscillators.

Pricing in quantities of 1 to 24 is: VFQ-2C, \$12.50; VFQ-3C, \$4.95. For more information, contact Datel-Intersil, 11 Cabot Blvd., Mansfield, MA 02048. CIRCLE 45

Classified Advertising

DESIRE work in Robotics. Soon to have BSME from CPSU. Resume on request: Michael Corliss; 1330 Southwood #11; San Luis Obispo, CA 93401.

HTS Timestack Kim/Aim/Osi products. Timestack Operating System implements programmable time-based controller. Software manual—\$20; User manual—\$5. Real-time clock hardware /software /interface manual documents program/circuitry—\$10. General expansion board adds 8K memory, 32 port lines. Construction manual details variations for 2114/6116 Ram, 2716/2732 EPROM, 6522/6532/6821 ports—\$10. Specify system. Information—\$1. Hunter Technical Services; P. O. Box 359; Elm Grove, WI 53122.

MICROBOT Minimover-5 complete with TRS-80 Level II computer and manual. Almost new. \$1400. Clint Green; 213/446-4994.

SONAR circuit plans: compact device is inexpensive to build and perfect for mobile robot use. Measures distance to detected objects up to fifteen feet away. Detailed plan set includes both microprocessor-interface and LED display versions, all for \$6.95. Write Sensystems, Box 1497, Cupertino, CA 95015.

Travelling To The West Coast Computer Faire?

If you are planning to attend the next West Coast Computer Faire, be sure to stop by at the Robotics Age booth, #1006 in the Brooks Hall section of the exhibition at the San Francisco Civic Center Auditorium. The Faire this year is being held on March 19, 20 and 21. The booth will be covered during show hours by Robotics Age Editor Carl Helmers, Associate Editor Ray Cote, Publisher Glen Swanson and Technical Associate Walter Banks.

Classified Advertising

Robotics Classified Advertisement Order Form

Robotics Age classified advertisements reach thousands of people interested in designing and developing intelligent machines. To place a classified ad simply fill out the order form below and mail to *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, N.H. 03458. The current word rate is \$0.50 per word and can be paid by check, MasterCard, or VISA.

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The New Robotics Age Robot Information Service is coming!

Placing classified advertisements will soon be even simpler with our Robot Information Service. This system will be on-line 24 hours a day with a 300 bps Bell 103A compatible modem. Anyone with a terminal or computer connected to a standard originate modem will be able to call the Robot Information Service and place a classified ad which will be billed to their MasterCard or VISA account. On-line editing allows text to be entered and verified before a final copy is saved for publication. Billing information is provided immediately so you know exactly how much your credit card account will be billed.

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DESKTOP 68000 + TELESOFT¹ ADA⁴ + PASCAL = **POWER**

THE IN/7000D BRINGS OUT OF THIS WORLD A/I PERFORMANCE WITHIN REACH

68000 BASED IN/7000D

Dramatically increased processing speed and flexibility:

- 8 MHz 68000 CPU
- 32-Bit internal arithmetic registers
- 24-Bit address register
- Powerful assembly language instructions support modular programming
- Designed for expansion to 32 bit word size
- 8 Levels of interrupt priority
- Vectored interrupts and DMA fully supported
- Outbenchmarks the IBM 370/145^{2*}
- High speed string processing

Vastly increased memory:

- 68000 directly addresses 16 MB of memory
- Sorts can be done in core rather than with disk I/O

PASCAL AND TELESOFT¹ ADA⁴

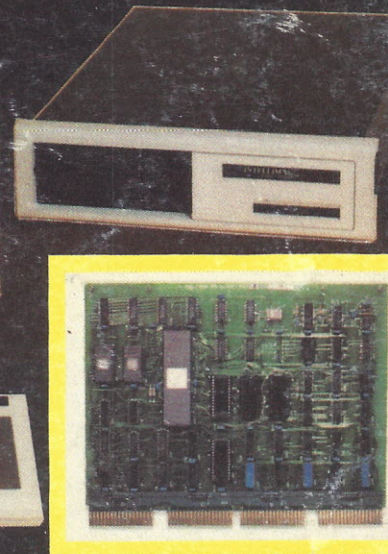
- Fast program development
- Self documenting
- Supports structured programming
- Easy to update
- Easy to maintain
- Transportable from computer to computer
- Powerful logical constructs greatly simplify programming

For example: Modular procedures and functions
Strong data types
Case structures

- Local and global variables
- Recursive problem solving
- Block insert — a block of statements may be inserted anywhere one statement can exist
- Built in Boolean functions
- Library capability
- Program segmentability
- Procedure linking
- TeleSoft¹ Pascal and TeleSoft¹ Ada⁴ translate to 68000 native code
- Built-in powerful string handling features

TELESOFT¹ ADA⁴

- Designed to fulfill all DoD specifications
- INTRINSIC functions include:
 - * Multi-tasking and multi-programming
 - * Independent compilation of program units (called Packages)
- Fully implemented syntax checker which now parses the entire Ada⁴ language



COMPATIBILITY WITH DEC Q-BUS³
AND STANDARD DEC⁴ PERIPHERALS

Saves development time.

- High speed sensory data processing
- High speed string processing power
- Fast coordinate transformations
- Easy implementation of in-memory AI algorithms, predicate calculus and trajectory computations
- Design and test algorithms quicker and easier
- Both Pascal and 68000 support features that make programming far more efficient
- Plenty of memory, no need to use extra time for "programming tricks," previously needed with limited memory
- Mixed mode listing (Pascal source statements followed by 68000 statements)

UP TO 4 MByte OF RAM

¹"Kilobaud Microcomputing" October, 1980

²A trademark of Renaissance Telesoftware Inc.

³A trademark of International Business Machines

⁴A trademark of Digital Equipment Corporation

⁵A trademark of Department of Defense

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